CALIFORNIA
ENERGY
COMMISSION

# PowerGuard® California: Advanced Manufacturing Development

CONSULTANT REPORT

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# CALIFORNIA ENERGY COMMISSION


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## Legal Notice

# Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Strategic Energy Research.

What follows is the final report for the Advanced Manufacturing Development project, #500-97-049 conducted by PowerGuard California. The report is entitled PowerGuard California: Advanced Manufacturing Development. This project contributes to the PIER Renewable Energy program.

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

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# Executive Summary

Recent threats of power shortages and rising energy bills clearly demonstrate that California needs more power generation capacity. Demand for power in California is expected to increase significantly in the next few years. Increasingly, California's consumers are demanding power from clean and reliable sources. Through funding assistance from the California Energy Commission's Public Interest Energy Research Program (PIER), PowerLight Corporation is making solar power more affordable and at the same time offering additional value by extending roof lifetimes and providing buildings with added thermal insulation benefits.

In the past, the main problem with generating electricity from the sun through photovoltaics (PV) has been cost. By investing in solar energy generating technologies, the California Energy Commission has contributed to creating the current market conditions in which PV makes not only environmental sense but economic sense as well.

Solar powered installations spare the environment from thousands of tons of harmful emissions, such as nitrogen oxides, sulfur dioxide and carbon dioxide, which are major contributors to smog, acid rain and global warming. A recently installed 1.2MW PowerGuard system in Dublin, California will reduce emissions of nitrogen oxides by an estimated 24,000 pounds and carbon dioxide by 38,000 tons. At the same time, projects such as this have generated an internal rate of return for the customer of over 10 percent.

In the three years of the PIER contract, "PowerGuard® California: Advanced Manufacturing Development," PowerLight Corporation (PowerLight) has gone from producing a small number of PowerGuard tiles largely by hand and one at a time to full-scale, high quality, high volume production using custom designed machinery. The accompanying photographs show the distinct contrast in production environment at the beginning of the contract in 1998 and near the end of the contract in 2001.


**Figure 1. PowerGuard 100kWp System**


**Figure 2. PowerGuard Manufacturing prior to PV:MaT funded improvements**

**Objectives**

The goal of this contract was to reduce PowerGuard system cost and improve system reliability through:

- Advanced fabrication equipment, increasing production capacity and reducing labor costs;
- Redesign and development of an inverter controller with data-acquisition and dial-up communication features for monitoring system performance;
- Development of PowerLight's in-house capability to fabricate PowerCurb housings;
- Refinements to manufacturing processes for other PowerGuard product features;
- Ensuring that PowerGuard systems, as modified under this contract, will continue to receive certifications from specific independent testing and certification entities.

**Outcomes**

During Phases I and II of the contract, PowerLight developed the PowerGuard system and manufacturing process for high volume production and cost reduction, while improving product quality. During Phase III, PowerLight expanded market penetration through strategic commercial alliances and receipt of necessary commercial certifications.

Over the course of this contract, production rates rose from 200 tiles per 8-hour shift to more than 500 tiles per 8-hour shift. The overall system cost of PowerGuard was reduced by 38 percent. The original goal of a 46 percent reduction was not met, due to unexpectedly high global demand for PV laminates, and limitations on supply. PowerLight has successfully reduced Balance of System (BOS) costs, including the cost of installation; at the end of this contract, BOS costs had been reduced by 68 percent. As PV laminate supply increases and the per-watt cost falls, PowerGuard will become even more affordable.

PowerLight has also continued to address quality issues by working on continuous improvement of tools and processes. Many aspects of factory operation have been improved, which has helped reduce overall costs. Increased demand for PowerGuard, which has been generated in part by cost reduction measures of the earlier phases of this project, has moved PowerLight into continuous production. This has allowed a shift from a temporary work force hired for each job to a full time production staff, improving product quality and further cutting costs by reducing the need for training.

In addition, PowerLight met project goals through:

- Implementation of a tile manufacturing facility, in Berkeley, California, exceeding 16-MW/year capacity;
- Improved quality of finished goods due to improved tooling and processes in PowerGuard manufacturing which also simultaneously improved throughput and lowered costs;
- Completion of wind tunnel testing of all design refinements and testing of PowerGuard installations on mechanically attached roof membranes;
- Creation of an installation manual and training program for installing PowerGuard systems;

- Certification and listing of PowerGuard products with Underwriters Laboratories and international certification organizations, and application for listing with the International Conference of Building Officials (ICBO).

**Figure 3. PowerGuard Manufacturing after PV:MaT funded improvements**

## Conclusions and Benefits to California

The work done by PowerLight under this contract to make this dramatic advance has greatly contributed to PIER Program objective of improving the reliability of California's electricity system by developing distributed-energy technology. This contract has also contributed to the PIER Program objective of reducing environmental risks from California's electric system by deploying a renewable energy source, which does not emit NOx (nitrous oxides), SOx (sulfur oxides), and CO2 (carbon dioxide) when generating electricity. Lastly, this contract has positively impacted California's economy by creating new manufacturing jobs. PowerLight's focus for this contract was its patented PowerGuard building-integrated PV roofing tile.

Increasingly, California's consumers are demanding power from clean and reliable sources. Through funding assistance from the California Energy Commission's Public Interest Energy Research Program (PIER), PowerLight Corporation is making solar power more affordable and at the same time offering additional value by extending roof lifetimes and providing buildings with added thermal insulation benefits.

Investments in solar power provide benefits to all Californians, including

- Economic development and associated jobs;
- A domestic source of energy that is plentiful, sustainable, and available throughout the United States;

- Transformation of clean, abundant solar energy into electricity by a process that is virtually maintenance free;
- An economic hedge against volatile fossil fuel prices, now and in the future;
- Renewable power for over 30 years, which can offset purchases of expensive “peak” utility electricity;
- An energy source that spares the environment from thousands of tons of harmful emissions, such as nitrogen oxides, sulfur dioxide and carbon dioxide, which are major contributors to smog, acid rain and global warming; and
- Distributed power at the end-user level so that transmission losses are reduced or eliminated and excess generation is returned to the grid for local usage.

# Abstract

PowerLight Corporation (PowerLight) has completed its PIER contract, “PowerGuard® California: Advanced Manufacturing Development.” The overall technical goal of this project was to reduce PowerGuard system cost and improve system reliability, contributing to the larger goal of making solar electric generation less expensive and more reliable. This document is the final report for this contract.

This report demonstrates how, over the course of this contract, production rates rose from 200 tiles per 8-hour shift to more than 500 tiles per 8-hour shift. The overall system cost of PowerGuard was reduced by 38 percent. The original goal of a 46 percent reduction was not met, due to unexpectedly high global demand for photovoltaic (PV) laminates, and limitations on supply. PowerLight has successfully reduced Balance of System (BOS) costs, including the cost of installation; at the end of this contract, BOS costs had been reduced by 68 percent. As PV laminate supply increases and the per-watt cost falls, PowerGuard will become even more affordable.

PowerLight has also continued to address quality issues by working on continuous improvement of tools and processes. Many aspects of factory operation have been improved, which has helped reduce overall costs. Increased demand for PowerGuard, which has been generated in part by cost reduction measures of the earlier phases of this project, has moved PowerLight into continuous production. This has allowed a shift from a temporary work force hired for each job to a full time production staff, improving product quality and further cutting costs by reducing the need for training.


**Figure 4. PowerGuard 32kWp Systems**

## 1.0 Introduction

### 1.1. Background and Overview

PowerGuard® building-integrated roofing tiles generates electricity from solar energy. With the assistance of PIER, PowerLight has improved the PowerGuard manufacturing process to lower costs, improve quality, and increase production capacity. By doing this, PowerLight met its overall goal to expand significantly the market for this product.

**Figure 5. PowerGuard Array During Installation**

A PowerGuard tile consists of a flat plate PV laminate mounted onto a flat, rigid, extruded polystyrene (XPS) board. Two edges of the XPS board are routed into a tongue profile and the other two edges are given a groove profile, allowing PowerGuard tiles to be assembled adjacent to each other in an interlocking fashion. Adjacent tiles are tied together electrically through connectors supplied on each PV module, thus creating a string of PV modules. One or more strings are then tied together electrically at a remote location creating a solar electric array (PowerGuard system). The resulting DC current from the array is passed through a DC/AC inverter and transformer before being tied into the building's electric service.

Through this contract, "PowerGuard Advanced Manufacturing," PowerLight introduced incremental improvements to PowerGuard system components and manufacturing processes to significantly reduce the costs of a PowerGuard system. This resulted in a lower cost, higher impact PV product – the goal of the PIER program.

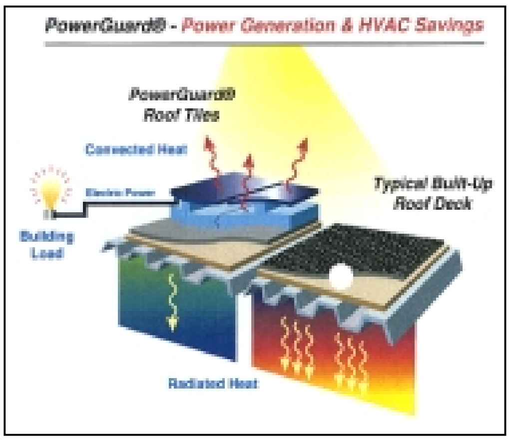


**Figure 6. PowerGuard Power Generation and HVAC Savings**

## 1.2. Project Objectives

The goal of this contract over its three-year duration was to continue the advancement of PowerLight PV manufacturing capabilities and provide PV systems incorporating financing options. PowerLight was to achieve the following objectives.

1. Cost reduction of 46 percent,
2. Complete manufacturing improvements for PowerGuard tile fabrication capability of 16-MW / year, and
3. Stimulate the expansion of US PV laminate manufacturing to 2-MW / year.

PowerLight was to address PowerGuard system cost reduction through the following:

- Improvements in manufacturing technology related to system (non-PV) components;
- Product design enhancements;
- Increased production capacity;
- Enhanced system reliability and performance;
- Strategic alliances to leverage PV module technical improvements and cost reduction.

## 1.3. Report Organization

Project Approach and Outcomes (Section 2.0) presents the contract scope of work and identifies the specific tasks performed. Each task is associated with a specific objective, which is stated. The results of each task are reported and conclusions discussed.

Conclusions and Benefits to California (Section 3.0) discusses the broader implications of the work performed under the contract.

# 2.0 Project Approach and Outcomes

## 2.1. Scope of Work

The scope of work under this contract included the following:

- Reduce the cost of a system 46 percent for large systems;
- Develop modular and standardized packages to reduce the cost of small systems;
- Develop design software to facilitate physical and electrical system design, system QA / QC, code conformity, permitting, and bidding;
- Produce an installation manual and training program for installing PowerGuard systems;
- Develop finance packages and integrated warranties for PowerGuard systems;
- Advance several design improvements to the grid-tied inverter control board, including controller redesign, integrated Data Acquisition System, and an auditable communications system to verify PV system performance;
- Complete improvements to PowerCurb™ retrofit (RT) housing, harness assemblies, and source circuit combining circuitry, to reduce costs (materials and labor) by 50 percent;

- Complete wind tunnel testing of all design refinements, including RT system securement, sloped tile assembly, and the field assembly system, to confirm Computational Fluid Dynamics modeling, and to establish wind zone design guides;
- Develop methods of packaging which lower packaging and shipping costs by 25 percent;
- Develop a sloped PowerGuard design;
- Apply for and / or finalize UL, International Conference of Building Officials (ICBO), and international certifications for PowerGuard improvements.
- Create a manufacturing layout master plan for sequential integration of semi-automated and automated component stations;
- Conform to National Environmental Policy Act (NEPA), Occupational Safety and Health Administration (OSHA), and other federal and state regulations applicable to the proposed production processes and mitigate potential for waste streams;
- Improve clean-up and waste management processes for PowerGuard production;
- Establish plant capacity dedicated to manufacturing 2-MW / year of PowerGuard; and
- Establish performance of manufacturing modifications based upon assessment of commercial systems that incorporate the new features and processes.

## 2.2. PHASE I (of III)

### 2.2.1. Task 1.0: Assembly Layout and Integration

#### 2.2.1.1. Objectives

Under this task, PowerLight and its contractor were to engineer a step-by-step approach to develop cost-effective, integrated automation of the PowerGuard tile manufacturing line, to increase the production rate from 100 tiles / shift to 200 tiles / shift by mid-1999. The automated line was to meet the following criteria: throughput improvement of 125-150 percent (from 12 minutes / tile); 10-40 percent reduction in number of operators (from 10); 30-55 percent reduction in tile cost (from $4 / board); and compliance with NEPA and OSHA.

#### 2.2.1.2. Results

The interim production rate goal of 200 tiles / shift (2.4 minutes per tile) – an 80 percent improvement – was met. Tile cost was reduced by 30 percent. The number of operators increased from 10 to 16.

#### 2.2.1.3. Discussion

Prior to the start of this contract, PowerGuard production rate was 40 tiles per shift (12 minutes per tile) and was done mostly with hand tools and simple jigs. PowerLight created a manufacturing master plan detailing the required resources for achieving the project goals. An automated manufacturing line was designed, and a location was found to set up the new manufacturing facility. The new manufacturing line was implemented, and the interim production rate goal of 200 tiles / shift (2.4 minutes per tile) – an 80 percent improvement – was met. Tile cost was reduced by 30 percent.

The number of operators increased from 10 to 16. At the end of Phase I, much of the equipment was installed but not yet commissioned, and extra people were required to perform the work. As the commissioning and “check out” process continued and was completed, in Phase II, the number of operators decreased (see Section 2.3.1).

By the end of the first year, PowerGuard tiles flowed in a continuous stream off the end of PowerLight’s new production line. Tile quality was much more consistent and cost was reduced despite a need for more labor than anticipated.

### 2.2.2. Task 2.0: PV Laminate Preparation

Under this task, PowerLight was to design and evaluate several automated stations for preparation of the PV laminates at the upstream end of the PowerGuard production line.

### 2.2.3. Task 2.1: J-box Attachment

#### 2.2.3.1. Objectives

PowerLight was to design, implement, evaluate, and determine the cost-savings resulting from an in-line, semi-automated station for J-box attachment. The station was to meet the following criteria: throughput improvement of 60-80 percent (from 10 min / laminate); decrease in shipping costs of laminates by 30-70 percent (from $.04 per Watt (peak) (WP) for high-efficiency laminates and $.08 / Wp for low-efficiency laminates); and compliance with NEPA and OSHA.

#### 2.2.3.2. Results

A mock-up of the station showed a reduction in the time required to attach the J-box was only 12 percent instead of the 60 percent-80 percent objective. Analysis based on the mock-up trials showed a potential $.04 / Wp savings in shipping, but tooling proved to be cost prohibitive.

#### 2.2.3.3. Discussion

A J-box attachment station was designed and a mock up created to test the design and assess the cost savings. Based on projected savings, the station was not implemented, because the tooling was too costly; the PV manufacturer avoids this problem by combining J-box attachment with other related activities. A cost / benefit analysis based on the mock-up trials showed a potential $.04 / Wp savings in shipping. Reduction in the time required to attach the J-box was only 12 percent instead of the 60 percent-80 percent objective.

### 2.2.4. Task 2.2: Electrical Quick Connects

#### 2.2.4.1. Objectives

PowerLight was to design, implement, and evaluate an automated harness assembly station for fabricating selected electrical connectors into tile electrical leads. This station was to be set up in Saugerties, NY, or Berkeley, CA, and its performance evaluated with trial or actual production runs. The result was to be a 50 percent cost-reduction.

#### 2.2.4.2. Results

Cost was reduced by 56 percent.

#### 2.2.4.3. Discussion

PowerLight identified a lower cost replacement for the connectors previously used. The new connectors provided significant cost savings, better waterproofing, and easier field repair, and they allowed the use of pneumatic assembly tools in the PowerLight factory. These tools were purchased and set up in the Berkeley facility. The first tool automatically cuts and strips wires to the correct length. The next tool crimps on the appropriate connector. The final tool installs the insulating boot over the crimped-on connector. The implementation of these tools and the switch to the new connectors reduced costs by 56 percent.

### 2.2.5. Task 2.3: Adhesive Priming

#### 2.2.5.1. Objectives

PowerLight was to design and implement an automated alcohol-wipe station, fully or semi-automated, and evaluate its performance with trial or actual production runs. The result was to be a 50 percent reduction in the number of operators needed.

#### 2.2.5.2. Results

Labor was reduced by 50 percent.

#### 2.2.5.3. Discussion

PowerLight commissioned the design for an automated adhesive priming station but was unable to implement this station during Phase I. The focus shifted to reducing the labor required for the priming task. The required labor was reduced from one full time worker to one half time worker. This system was used during all the production runs during Phase I of this project.

### 2.2.6. Task 2.4: Module Quality Control Testing Station

#### 2.2.6.1. Objectives

PowerLight was to design and implement a semi-automated testing station for final testing of laminates prior to tile assembly. Its performance was to be evaluated with trial or actual production runs. The result was to be an in-line testing station that electrically confirms both voltage and current prior to assembly.

#### 2.2.6.2. Results

A Quality Control station was constructed and is in use during PowerGuard production.

#### 2.2.6.3. Discussion

PowerLight constructed a PV Module test station with an artificial light source and meters to display voltage and current output. This system is currently used to test every PowerGuard tile before it is packaged for shipping. The test verifies basic function of the PV laminate and insures that the electrical leads and connectors are properly installed. This test station is positioned over a section of roller conveyor so that the completed PowerGuard tiles can be rolled into position. The leads are then connected and the lights are turned on. The whole process takes only a few seconds per tile.

### 2.2.7. Task 3.0: Extruded Polystyrene Processing

#### 2.2.7.1. Objectives

Under this task, PowerLight was to evaluate options for redesigning the hot knife cutting station then in use with a router station for cutting the tongue and groove profile into the extruded polystyrene (XPS) boards. PowerLight was to design, implement, and test the equipment and then evaluate station performance with trial or actual production runs.

Table 1 presents the criteria that the XPS processing station was to meet.

**Table 1. XPS Processing Station Criteria**

| Criterion | Existing | Expected Improvement |
|---|---|---|
| **Throughput (minutes/laminate)** | 2 | 30%-70% |
| **Number of Operators** | 2 | 50% |
| **Tolerance: board square** | 1/8” | 40%-75% |
| **Tolerance: board lengths** | 1/16” | 50%-75% |
| **Tolerance: tongue and groove** | 1/16” | 50%-75% |
| **NEPA, OSHA compliance satisfied** | | Yes |

#### 2.2.7.2. Results

The router station was designed, implemented, and tested. All criteria were met (or exceeded) except for throughput, which improved 25 percent.

#### 2.2.7.3. Discussion

After researching options for this station, PowerLight purchased a CNC dual head router with a vacuum table. The router has a positioning accuracy of ±0.002”. This produces board dimensions much more accurately than the previous methods used to make PowerGuard backerboards. This router uses two cutters, one for the tongue profile and one for the groove profile. Previously, each board edge required two cutting operations: one to cut the tongue or groove profile, and a second to cut the rabbet on the top of the board. The new cutters cut the tongue or groove and the rabbet at the same time. This insures that the profile cut into each edge or each board matches the exact profile called for in the specification.

Operation of the router requires one worker, reducing labor by 50 percent. Boards cut on the CNC router vary in dimension by less than 0.015”, which is better than the desired 75 percent improvement. The loading and unloading of the router is still a slow process, so the best throughput achieved was approximately 1.5 minutes, or a 25 percent improvement.

### 2.2.8. Task 4.0: Automated Coating Station

#### 2.2.8.1. Objectives

Under this task, PowerLight was to design, implement, and evaluate an automated station for coating the top surface of the XPS boards. Development of this station was targeted as essential for production volume to grow from 100 to 400 tiles / shift. Table 2 presents the criteria that the coating station was to meet.

**Table 2. Coating Station Criteria**

| Criterion | Existing | Expected Improvement |
|---|---|---|
| **Throughput (minutes/board)** | 12 | 65%-85% |
| **Number of Operators** | 4 | 60%-80% |
| **Coating uniformity (thickness tolerance)** | 1/8" | 50% |
| **NEPA, OSHA compliance satisfied** | | Yes |

#### 2.2.8.2. Results

Throughput increased to faster than 1 minute per board. The new station requires 1 full time operator and 1 helper half of the time. Coating thickness is held consistent to ±0.063". The station is NEPA and OSHA compliant.

**Figure 7. XPS Board Coating Station**

#### 2.2.8.3. Discussion

During this period, numerous alternatives to the current coating were identified and investigated. A cementitious coating was selected due to its expected durability and low cost. A coating mixture was optimized for maximum resistance to cracking, warpage, chipping, and freeze thaw damage. PowerLight worked with the National Renewable Energy Laboratory (NREL) to develop a freeze-thaw testing regimen in accordance with accepted industry testing standards.

An automated coating, mixing, and application station was designed and built. Since implementation, it has been used in actual production runs to coat more than 30,000 boards of various sizes. Boards are coated at a rate of 1 board per minute or faster – a tremendous improvement over the previous method which coated 1 board every 12 minutes. The station requires 1.5 operators (1 full time operator and 1 helper who spends 4 hours per shift at the station) for a reduction of 2.5 operators over the previous method. Finally, the coating thickness is very consistent at ±0.063" and does not change with production line speed.

### 2.2.9. Task 5.0: Automated Spacer Attachment (Flat Tile)

#### 2.2.9.1. Objectives

Under this task, PowerLight was to design, implement, and evaluate automated equipment to attach spacers to the XPS backerboard for PV laminate stand-off. PowerLight was to design and review current options and research alternative spacer materials. The result of this task was to be the selection and specifications and estimated cost savings for the automated equipment.

#### 2.2.9.2. Results

Spacer materials were selected. Attachment equipment was designed and implemented. Cost savings are greater than 50 percent.

#### 2.2.9.3. Discussion

Possible spacer materials were evaluated based on the following criteria:

- Low cost;
- +30 year life expectancy;
- PV able to be removed from spacer intact after attachment;
- Structural performance of 50 lb / sf tension and 200 lb / sf compression;
- Enhance aerodynamic properties (as per wind tunnel studies);
- Enhance low temperature operation of PV laminate (better air-flow under and around the laminate results in lower temperature, higher efficiency operation);
- Flame resistant (non-flammable);
- Withstand high temperature;
- UV resistant;
- Withstand a freeze / thaw environment;

- Adhere to XPS board or to coating of 50 lb / sf or better;
- Adhere to PV (glass or Tedlar) of 50 lb / sf of better;
- Allow PV attachment in the factory or in the field;
- Allow stacking of assembled tiles while coating is still wet;
- Allow for continuous coating of board.

The spacer material that met all criteria was XPS foam, in blocks. More than 10,000 spacers have been fabricated with the first spacer fabrication station. One operator produces 4 spacers in 2 minutes, resulting in almost 1000 spacers per shift.

### 2.2.10. Task 6.0 Inverter Controller Improvements

#### 2.2.10.1. Objectives

Under this task, PowerLight and its lower-tier subcontractor Xantrex Technologies (formerly Trace Technologies) were to evaluate and modify the Xantrex inverter controller, integrate a data acquisition system (DAS), and incorporate dial-up communication capability into the Xantrex Solar Control Unit (SCU). Xantrex was to replace analog circuitry with digital circuitry and eliminate non-PV-related functionality. In addition, circuit board revisions were to be incorporated into the controller to reduce parts count and cost. The DAS was to incorporate analog inputs for weather-related sensors, and non-volatile storage was to be embedded in the controller for logging data.

The result was to be an SCU with an integrated inverter / DAS package for grid-tied PV applications with dial-up communications. Parts count was to be reduced by approximately 50 percent and reliability was to double. The final parts count was expected to decrease by 75 percent and the calculated Mean Time between Failures (MTBF) was expected to increase 33 percent, from 44,000 hours (5 years) to 59,000 hours. The DAS was to record DC voltage and current, DC power, AC power, ambient temperature, wind speed, insulation, and module and membrane temperatures.

#### 2.2.10.2. Results

Parts count was reduced by 50 percent. All other objectives were met.

#### 2.2.10.3. Discussion

The first prototype SCU was installed at the PowerLight factory in Berkeley in April of 2000. Its features are as follows:

- Parameters for the inverter can be modified offsite from the Graphic User Interface (GUI). This significantly reduces both travel time and system downtime, since the inverter can be reset remotely if it faults or if a parameter needs to be modified.
- Analog inputs for the meteorological sensors have been incorporated. The system can log six such sensors. Currently, only three are used, for ambient temperature, wind speed, and irradiance. Limiting the number of inputs and functionality has reduced the cost of the SCU by 6- 48 percent depending on its size compared to a conventional datalogger.

- Circuitry and functionality not related to PV have been eliminated from the inverter and the number of parts has been reduced by 50 percent.
- Remote access over a dial-up connection has been incorporated.

### 2.2.11. Task 7.0: Sloped Tile Manufacturing Design Improvements

Under this task, PowerLight was to improve product design to take advantage of new/alternative products and materials. These advancements are detailed in the three subtasks discussed below.

### 2.2.12. Task 7.1: Sloped Tile Assembly

#### 2.2.12.1. Objectives

PowerLight was to refine the design of a module spacer assembly to simplify the design, make the assembly easier to manufacture, and allow tiles to ship flat and tilt to slope in the field, all while minimizing additional costs. The result of this task was to be an assessment of an integrally designed spacer mechanism for sloped PowerGuard tiles that meet the following criteria:

**Table 3. PowerGuard Tile Criteria**

| Criterion | Existing | Expected Improvement |
|---|---|---|
| **Design life** | 5 years | 20 years |
| **Cost per tile** | $35 | 20-50% |
| **Shipping height** | 10” | 100-150% |

#### 2.2.12.2. Results

The new design has a design life of 30 years. Cost goals were met, and the shipping height is only 4.5”.

#### 2.2.12.3. Discussion

An extensive design effort led to a production prototype for a “pop-up” sloped-tile assembly. Custom sheet metal parts replaced more expensive hinges and mechanisms. Wind tunnel testing proved that these parts, with some modifications, were structurally sound. The collapsed tile was less than 4.5” tall; it has an expected 30-year life.

Cost objectives were nearly met with this first version. However, further design options were investigated, with the aid of a product design consultant, resulting in an improved design. Research and field-testing show that the resulting new design meets design and performance criteria and will meet European product standards.

The design consists of just four parts in addition to the PV laminate and the coated backerboard. Cost is reduced because the materials are shipped flat to the factory. Perforations in the sheet metal make bending straightforward and repeatable with the help of simple jigs. Three metal strips are bent and attached to the coated board. The wind deflector includes legs which support the PV laminate and the deflector at the top edge of the slope. Figure 8 and Figure 9 shows the design.

**Figure 8. Sloped Tile Base Strips**

**Figure 9. Sloped Tile Base Strips and Deflector Completely Assembled**

### 2.2.13. Task 7.2 a-Si Tile Packaging

#### 2.2.13.1. Objectives

PowerLight evaluated modifications required to manufacture an advanced PowerGuard tile that uses the Solarex amorphous-silicon (a-Si) PV laminates. The low temperature coefficient of a-Si and the seasonal enhancement due to annealing provide the possibility of a PowerGuard tile which is uniquely low-profile yet operates at higher temperatures.

The result of this task was to be a prototype tile design achieving a 10-20 percent reduction in board fabrication costs while maintaining a 30 year design life and not exceeding laminate temperatures of 90°C.

#### 2.2.13.2. Results

Measurements of PV temperature on a PowerGuard tile constructed with 1” spacer height and an a-Si module showed maximum temperature of 77°C. Board fabrication cost was not reduced significantly, though shipping costs were improved by 15-20 percent.

#### 2.2.13.3. Discussion

Several prototype tiles were constructed and tested using a-Si laminates mounted on spacers of various heights. While the spacers could not be eliminated, it was discovered that a 1” spacer results in sufficient cooling of the PV laminate such that performance is not compromised.

Laminate temperatures were observed to reach 77°C (170°F). The resulting tile was 3.25” tall, a full 2” shorter than typical PowerGuard tiles. Shipping density improved as PowerGuard tiles could be stacked 16 per pallet instead of the usual 12. This improvement reduces shipping costs by 15-20 percent. The cost improvement of the tile itself is minimal, because the labor to fabricate and install 1” spacers is the same as installing taller spacers, and material savings are insignificant. This design could not achieve the desired 10-20 percent cost reduction.

### 2.2.14. Task 7.3: Retrofit PowerCurb™

#### 2.2.14.1. Objectives

PowerLight was to investigate alternative designs for the Retrofit (RT) PowerCurb housings (PowerGuard roof tile retrofit mounting) prior to committing to a manufacturing plan. (PowerGuard RT mounting is the array perimeter securement used when PowerGuard is installed as a retrofit island on an existing roof, as opposed to installing with LightGuard® pavers covering the rest of the roof, as in new construction applications.)

The result of this task was to be a PowerCurb design that met certain criteria (Table 4).

**Table 4. Design Criteria**

| Criterion | Existing | Expected % Improvement |
|---|---|---|
| **Unit cost ($/linear ft)** | $8 | 40-60% |
| **# part types in assembly** | 6 | 50% |
| **Passes Class A fire tests** | | Yes |
| **Close packing for shipping** | | Yes |
| **20 yr. design lifetime** | | Yes |

#### 2.2.14.2. Results

With the new design, costs were reduced 50 percent, and the number of parts fell from 6 to 2. All other design criteria were met.

#### 2.2.14.3. Discussion

The final design was composed of two parts: a galvanized sheet metal pan and a custom shaped concrete curb. Concrete curbs would be manufactured using either a wet cast process or an extrusion process. The curbs would replace the blocks as ballast. The curbs would have the same aerodynamic profile as the sheet metal housing, eliminating the need for the housing and reducing material cost, as concrete is much less expensive than bent sheet metal. Costs were reduced 50 percent, and the number of parts fell from six to two. Further cost reduction was part of Phase II.

### 2.2.15. Task 8.0 Environment, Health, and Safety

#### 2.2.15.1. Objectives

Under this subtask, PowerLight was to incorporate federal and state regulations applicable to the proposed production processes, system installation practices, and system operation; evaluate options to reduce wastes and hazardous substances; and investigate opportunities to use recycled materials.

#### 2.2.15.2. Results

PowerLight met all the objectives of this task as listed above.

#### 2.2.15.3. Discussion

A report was produced with a summary of relevant state and federal regulations. PowerLight then took the following steps to implement the safety systems required by these regulations.

In accordance with California Occupational Safety and Health Administration (CAL/OSHA), an Injury and Illness Prevention Program has been in place at PowerLight facilities for some time (T8 CCR, Section 3203). Emergency and fire plans are in place in compliance with Title 8, sections 3220 and 3221. A training program for factory workers was implemented with a focus on mandatory training for noise protection (section 5099), personal protective devices (3380), medical services and first aid (3400), and respiratory protection. A Hazard Communication Standard was established in accordance with CAL/OSHA General Industry Safety Order (GISO) 5194. NOTE: PowerLight's use of hazardous or toxic chemicals is extremely limited per the Environmental Protection Agency's "Designation of Hazardous Substances" (40 CFR Part 116) and CAL/OSHA's "Hazardous Substance List" (Chapter 3.2 Article 5 Part 339).

PowerLight maintains a copy of these regulations as a reference for design staff.

### 2.2.16. Task 9.0: Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

#### 2.2.16.1. Objectives

Under this subtask, PowerLight was to conduct wind tunnel testing on prototypes of all modifications to the PowerGuard tile system.

#### 2.2.16.2. Results

Aerodynamic improvements were made to the sloped PowerGuard tile design. Additionally, wind tunnel tests showed that design changes implemented during the first phase of this PIER contract have neither degraded nor improved PowerGuard's ability to withstand 140 mph winds on most buildings.

#### 2.2.16.3. Discussion

PowerLight conducted testing on aerodynamically accurate models of PowerGuard systems installed per specifications on model buildings. Sensitivity to array size, PV slope, curb weight and shape, array location on roof, building and parapet height, presence of water on the roof, high-wind securement options, roof texture, and wind direction were studied. Failure criteria were established. Friction coefficients of PowerGuard system components on various roof surfaces were measured for modeling in the tunnel and for structural analysis. Aerodynamic improvements were made to the sloped tile, including reducing the uplift coefficient by 50 percent without increasing drag coefficient or tile cost. Sensitivity of failure velocity to building and parapet height, array orientation on roof, array size, and curb design were also studied.

### 2.2.17. Task 10.0: Underwriters Laboratories (UL) Listing

#### 2.2.17.1. Objectives

Under this subtask, PowerLight was submitted modified products to UL for listing. These products include the sloped tile assembly, a-Si packaging, RT PowerCurb, electrical quick-connects, new adhesives and/or coatings, and source circuit circuitry.

#### 2.2.17.2. Results

Several products were submitted to UL for testing during Phase I of this project. The complete list of products that received UL listing during the course of this project are shown in section 2.4.4.

#### 2.2.17.3. Discussion

PowerLight submitted the following PowerGuard prototypes to UL for testing and listing during Phase I of this contract: five different frameless PV modules, an a-Si PowerGuard tile, the selected electrical quick-connects for PowerGuard tiles, a new field combiner box, and PowerGuard RT system specifications.

### 2.2.18. Task 11.0: International Certifications

#### 2.2.18.1. Objectives

Under this task, PowerLight was to work to receive appropriate listings and marks for candidate international markets, including Japan, Germany, Austria, Australia, Switzerland, Italy, Spain, Mexico, Canada, and England. PowerLight was to submit selected products for the listing or mark for one or more countries.

#### 2.2.18.2. Results

PowerLight investigated the appropriate listings and marks for candidate markets, including Austria, Australia, Canada, England, Germany, Italy, Japan, Mexico, Spain, and Switzerland.

Certifications in Japan were initiated. A license partner was identified, and codes were acquired through the Japanese Ministry of Construction.

### 2.2.19. Task 12.0: Integrated Warranties

#### 2.2.19.1. Objectives

Under this task, PowerLight was to develop a PowerGuard comprehensive system warranty, including a service and maintenance option, integrating the warranties from PowerLight and component suppliers.

#### 2.2.19.2. Results

PowerLight developed a PowerGuard comprehensive system warranty, integrating warranties from the PV manufacturers, inverter manufacturers, and other system components. A service and maintenance option was also established.

### 2.2.20. Task 13.0: Assessment of Commercial Demonstrations – Phase I

#### 2.2.20.1. Objectives

Under this task, PowerLight was to assess the results of a commercial demonstration, minimum 40-kW, to demonstrate the improvements made under Phase I of this program. PowerLight was to evaluate system performance, review cost savings, and assess effectiveness of changes.

**Figure 10. PowerGuard tiles during installation**

#### 2.2.20.2. Results

PowerLight completed an assessment of improvements made to the PowerGuard product line and manufacturing process during Phase I of this project. The results of this assessment are detailed below. An assessment of this kind was made during each of the three phases of this project. A comparison of costs from the three assessments is detailed in section 2.4.7.

#### 2.2.20.3. Discussion

Ten identical 6-kW systems (60-kW total) were manufactured and installed for the New York Power Authority. A 7.7-kW system was installed at the State University of New York, New Paultz. A 28-kW system was installed for the Western Area Power Administration, Elverta, CA.

The new tongue and groove profile improved the ease of installation. The coating was found to be robust, i.e. there was no sign of warpage, shrinking, or chipping. Two key components required further improvements: the sloped tile assembly and RT PowerCurb. The Elverta system demonstrated that laminate strength is central to a-Si tile development. In the months after installation and commissioning of this system, more than 115 a-Si laminates were replaced due to cracking. This problem was primarily due to a flaw in manufacturing by the PV vendor.

## 2.3. PHASE II (of III)

### 2.3.1. Task 14.0: Assembly Layout and Integration

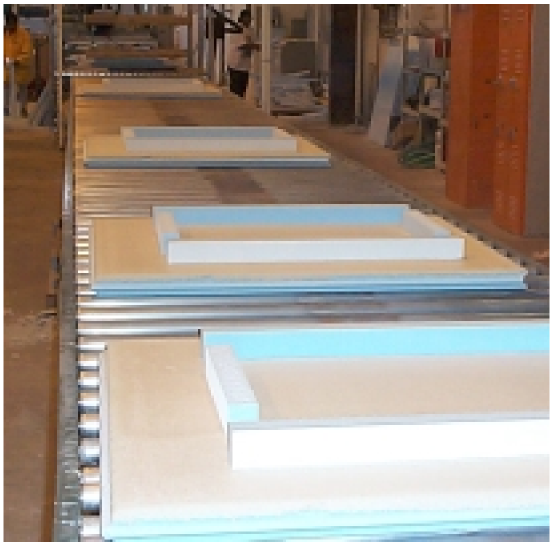

**Figure 101. PowerGuard Backerboard Fabrication**

#### 2.3.1.1. Objectives

Under this task, PowerLight continued efforts initiated in Phase I to complete the design and development of equipment for cost-effective, integrated automation of the PowerGuard manufacturing line. Specifically, the redesigned production line was to reduce system costs by 20 percent by meeting the following criteria: increase per shift production by 100 percent (from 200 to 400); increase throughput 40-60 percent (from 3 min / tile); decrease number of operators by 20-30 percent (from 8 operators); comply with NEPA and OSHA.

#### 2.3.1.2. Results

Advanced automation improved throughput and product quality. In sum, system costs were reduced 57 percent. The production rate improved more than 100 percent. Throughput time was reduced 80 percent. The process complies with NEPA and OSHA. The number of operators rose 50 percent: it was discovered that to lower the cost of finished goods, maximizing throughput is more important than minimizing labor.

#### 2.3.1.3. Discussion

Timing and quality studies completed at the end of Phase I revealed that production bottlenecks were being caused by problems with coating application and XPS spacer cutting. Both problems were solved through equipment and process redesign.

The original coating system was labor-intensive, delivered inconsistent quality, and thus limited throughput. The mixing machine now used delivers a consistent coating mix to the distribution hopper with minimal labor. The new hopper can be disassembled in just a few minutes with a minimum of tools, greatly decreasing cleaning time. Additionally, all adjustments are retained when the hopper is disassembled, so that setup for the next run takes only a few minutes. Coating quality has been improved and is much more consistent with the new hopper.

The original spacer cutting process was inconsistent. Engineers determined that with custom made bits, the computer numerical control (CNC) router could be used to cut spacers. With minimal modification to the router, operators are now able to cut spacers with less waste and greater accuracy. In addition, one worker can set up the stock, start the cycle, and do other work while the router runs, returning at the end of the cycle to reload.

### 2.3.2. Task 15.0: PV Laminate Preparation AC Tile Station

#### 2.3.2.1. Objectives

Under this task, PowerLight was to establish an AC module station for in-line attachment of module inverters to a PowerGuard tile.

#### 2.3.2.2. Results

PowerLight researched methods for attaching inverters to PowerGuard tiles, but the expected advances in palm size inverter technology did not materialize, making implementation inadvisable at this time.

#### 2.3.2.3. Discussion

PowerLight researched various methods for attaching inverters to PowerGuard tiles. It was determined that there are few extra steps that would be involved in the installation of the inverters. The inverters would be attached to the PV laminates and strain relief glands would be installed. The wiring would then be connected.

In order to remove knock-out hole covers in the housings without risking damage to the PV laminate, PowerLight developed a special punch tool so that no hammers would be used near the glass of the laminates.

Currently, the small, palm size inverters that would be needed for manufacturing AC tiles are not of acceptable quality for PowerLight to use in a commercial project. Prototype units installed in the field have not performed well. Until reliable, economical units are available on the market, PowerLight does not intend to continue this development effort.

### 2.3.3. Task 16.0: Automated Spacer Attachment (Flat Tile)

#### 2.3.3.1. Objectives

Under this task, PowerLight was to design, implement, and evaluate equipment to adhere XPS spacers to the XPS backerboard. The following criteria were to be met: 100 percent improvement in throughput (from 90 to 45 seconds per tile); one operator; improvement of position tolerance from ± 0.25” to ± 0.0625”; compliance with NEPA and OSHA.

### 2.3.3.2. Results

Throughput improvement exceeded expectations, decreasing processing time to 20 seconds or less per tile. Two operators are required for this station. This is short of the objective, but an improvement on the five operators required prior to these improvements as discussed below. Position tolerances stayed at 0.25", but changes in the process made this acceptable. This tolerance does not affect product quality. This station is in compliance with NEPA and OSHA.

### 2.3.3.3. Discussion

When PowerLight first opened its Berkeley factory, spacers were glued to the PV panels. This was done manually with two alignment jigs, used in parallel. At each jig, two people placed spacers on the PV panels. A fifth person applied glue to all spacers prior to their placement on the PV. This process was slow and labor intensive. The PV panels and spacers had to be stacked and weighted and then left to cure. These assemblies would then be attached to backerboards during the coating process.

The production method was redesigned so that spacers are attached to coated backerboards, and PV panels are attached to the tops of the spacers after the coating has cured. This improved process has resulted in increased throughput. Various methods of completely automating the positioning of spacers have been investigated, but they have proven prohibitively expensive. The goals for throughput and position tolerance can be met with a semi-automated system.

To insure that spacers are placed on the coated boards in a consistent manner, a semi-automated stop bar and alignment jig have been installed on the production line. An optical sensor detects the presence of a coated board at the alignment jig. One worker pushes the board against the alignment jig. A projector is mounted above the spacer placement station. This projects an image onto each board in the alignment jig showing clearly the positions of the four spacers with four bright rectangles. This allows the workers to position the spacers quickly and accurately as shown in Figure 12. If a board is detected at this station, the stop bar at the spacer placement station will not rise up to allow another board to enter. As long as the press station is clear, when the worker at the spacer placement station pushes the button, the stop bar will rise, allowing the board with spacers to move downstream to the spacer press. When the board clears the optical sensor, the stop bar automatically drops into position to wait for the next board.

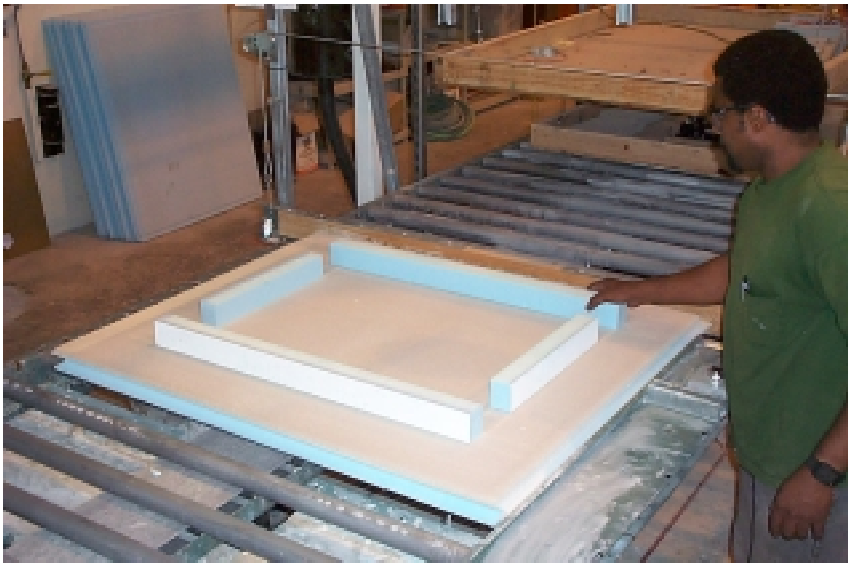

**Figure 12. Spacer Placement**

### 2.3.4. Task 17.0: Automated Spacer Attachment (Sloped Tile)

#### 2.3.4.1. Objectives

Under this task, PowerLight was to design, implement, and evaluate the performance of semi-automated equipment for attaching the sloped spacer components to the XPS backerboard. PowerLight was to design and specify the equipment for the coating station and evaluate station performance based on trial or actual production runs to achieve throughput of 2-5 minutes per tile and reduce the number of operators by 50 percent.

#### 2.3.4.2. Results

It was originally expected that when the design work was finished for the sloped version of PowerGuard, special equipment would be required to place the sloped tile spacers on the backerboards. However, with the final design, the method of spacer attachment is the same as for flat tile PowerGuard.

#### 2.3.4.3. Discussion

The spacers for the sloped tile consist of three long metal strips shaped to provide the base of the sloped tile. These are placed on the coated boards using the same equipment as that used for the flat tile, but the projected image is changed to match the three long metal spacers. The sloped tile design is shown in Figures 8 and 9 (see section 2.2.12).

### 2.3.5. Task 18.0: PV Module Placement

#### 2.3.5.1. Objectives

Under this task, PowerLight was to design and evaluate PV module placement equipment to apply adhesive and accurately position the PV module on the backerboard, and eliminate the need for curing racks by stacking the modules directly onto a shipping carton or pallet base.

The objectives of this task were a 50 percent throughput improvement, a reduction of labor, and a 50 percent improvement in positioning accuracy.

#### 2.3.5.2. Results

Completed tiles are stacked and cured directly on the shipping pallet. Throughput improved by more than 50 percent, while positioning accuracy was increased by more than 50 percent. Labor increased from one to two workers as discussed below.

#### 2.3.5.3. Discussion

Initially, goals were to increase throughput a modest amount and decrease the number of operators significantly by moving toward a completely automated system. As the work progressed, it became clear that reducing the cost of finished goods depended more on increasing throughput than reducing labor. Therefore, PowerLight focused on increasing throughput. With the new system, labor increased from 1 to 2 workers, because the tools to allow one worker to accomplish this task proved to be awkward and slow or prohibitively expensive. It was found to be more efficient to have two workers attaching the PV laminates. This provided an overall improvement in throughput and a resulting reduction in cost. Completed tiles are stacked directly onto shipping pallets for curing.

Several methods to place the PV modules onto PowerGuard backerboards were investigated. A conveyor line was set up to test the method of attaching PV panels to the spacers. In the first stage of equipment development, an alignment jig with a pneumatically powered articulated stop bar was placed on top of the conveyor. A backerboard with spacers is positioned in the alignment jig. Glue is applied to the top of the spacers, and the PV panel is laid on top. Operators wait for the glue to cure, then raise the stop bar and push the completed tile to the end of the conveyor where the tile is lifted and stacked on a pallet. When this pallet is full, weight is applied to the top until the glue has cured. The pallet is then wrapped for shipment.

This system was used for several production runs, and the quality of the PowerGuard tiles was consistently good. However, throughput was less than optimal.

The second stage of equipment development specifically addressed throughput. Engineers determined that most issues could be addressed using two custom jigs with integrated rollers to provide easy positioning of the backerboard. Each jig is only slightly bigger than the PowerGuard tile, which allows easy access to all sides. A vacuum hoist has been installed to allow one operator to handle the PV laminates.

A cured backerboard with spacers is placed on an alignment jig. Glue is applied to the spacers on the backerboard. The operator then maneuvers the vacuum hoist over to an alignment jig and places the PV laminate on top of the waiting backerboard (Figure ). That operator then retrieves another backerboard, places it on the other alignment jig, and then retrieves another PV laminate. At the same time, another operator moves between the alignment jigs with the glue dispensers. Once the PV laminate has been attached to the backerboard and the glue has cured, the tile is removed from the jig and stacked on the shipping pallet. Two stacking jigs have been constructed where one was used before. This allows the operators to continue without interruption. Once they have completed one stack, they move to the second stack, instead of waiting for the pallet to be removed from the jig and replaced with an empty one.

After each tile is placed in the stacking jig, the PV alignment is checked with a set of go / no-go gauges to insure proper alignment has been maintained. This step takes very little time and insures that the PV laminate is aligned with the backerboard to better than ±1 / 16”.

Using one alignment jig, workers were recently able to process PowerGuard tiles at the rate of one per minute. By using two jigs simultaneously, the throughput is doubled.

**Figure 13. Laminate Placed on Backerboard**

An additional jig was designed and constructed for handling PV laminates prior to adhesion to the tiles (Figure 11). The laminates are removed from their packing crate and set in the V-shaped jig if they need to be turned over. In this flip jig, the laminates can be leaned one way or the other, and then easily lifted using the hoist.

**Figure 114. PV Prep-and-Flip Jig**

### 2.3.6. Task 19.0: Advanced Packaging

#### 2.3.6.1. Objectives

Under this task, PowerLight was to specify and evaluate packaging for PowerGuard tiles. Goals were to maximize shipping efficiency, reduce costs, and provide easier handling, rigidity for product protection, and cost-effective return shipment to the factory. PowerLight was also to explore the use of recycled materials. Expected results were overall cost savings of 30-50 percent and an increase in shipping efficiency to the point where 90-100 percent of the available shipping volume is used.

#### 2.3.6.2. Results

Shipping volumes did not change, as an increase was not cost-effective. None of the alternatives to the present pallet was cost-effective. Improvements were made to reduce breakage during shipment. Because breakage was unpredictable, it is difficult to estimate cost savings.

#### 2.3.6.3. Discussion

To improve shipping efficiency, PowerLight experimented with filling more of the potential shipping space (e.g. in a transport truck). However, this caused loading and unloading to take longer, increasing labor costs. Current shipping methods proved more cost-effective.

Regarding pallets, historically, PowerLight has stacked and shipped PowerGuard Tiles on wooden pallets. The tiles were stretch-wrapped with protective cardboard edging on all 4 corners. The pallets were either returned by truck to the factory or disposed of at the destination.

Based on our studies, the best off-the-shelf replacement for a wooden pallet was a plastic stackable pallet, which would be returned by truck to the factory. These pallets would consume less space than wood pallets during return transit and in storage at the manufacturing facility, and they would be more roof friendly because they lack protrusions, splinters, and nails.

The best plastic pallet for PowerLight's needs is made from high-density polyethylene and can be recycled at the end of its life cycle, which is 20+ shipments of product depending on damage sustained during shipping. The pallet can be moved by a pallet jack or forklift. Use of these pallets would still require stretch wrap with corner protection.

Cost comparisons are as follows for the life cycle of the plastic pallet:

**Table 5. Cost comparisons for the Life Cycle of the Plastic Pallet**

| | Wooden Pallet | Plastic Pallet |
|---|---|---|
| **Size** | 48" x 40" | 48" x 40" |
| **Uses per unit** | 1 | 20 |
| **Cost of Pallet** | $4.80 | $16.00 |
| **Weight of pallet** | N/A | 35 lb. |
| **Cost of return shipping** | Not returned | $17.50 ($.50/lb rate) |
| **Total cost for 20 shipments** | $96 | $348.50 |
| **Cost per shipment** | $4.80 | $17.43 |

The shipping cost to return the pallets overwhelms any advantage that reusing them may provide.

PowerLight also investigated the possibility of making pallets with the polystyrene foam dust created by the cutting processes in the factory. A sample of the dust was sent to a company specializing in molding pallets out of reused material. A prototype was created, but the finished pallet weighed 80 lbs., more than twice as much as a wooden pallet, and would be very cumbersome.

Based on this information, wooden pallets still seem the best option for PowerLight at this time.

PowerLight has also made some packaging improvements to reduce breakage of PowerGuard tiles made with thin-film PV laminates. Thin-film PV laminates are made with untempered glass, and thus are more easily cracked or broken by rough handling. During shipping, some laminates had been broken in a way that indicated that they had been subject to flexing during shipping, and this seemed a result of the laminates not being supported at the edges. To address this problem, a foam and cardboard insert was created to help support the edges during shipping. The insert is made from an open-cell foam insert (Figure 12) cut to conform to the space between the PowerGuard tiles as they are stacked for shipping (Figure 13).

Test pallets of PowerGuard incorporating thin-film laminates were packaged with these new foam inserts and shipped across the country to determine if the new inserts reduced the amount of breakage. While breakage was not eliminated completely, there were no flexing failures as had been observed in previous shipments. These inserts are now used when PowerLight ships PowerGuard tiles made with thin-film laminates.

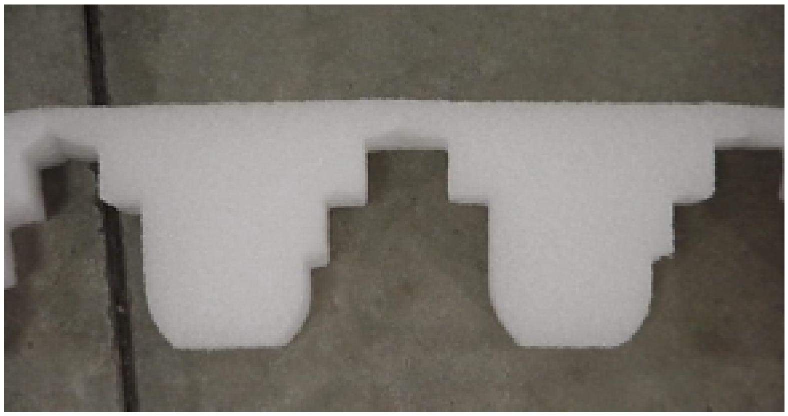

**Figure 125. Packaging Insert for PowerGuard with Thin-Film Laminates**

**Figure 136. Packaging Insert in Use**

### 2.3.7. Task 20.0: Materials Handling Between Stations

#### 2.3.7.1. Objectives

Under this task, PowerLight and its subcontractor were to develop additional motorized conveyors and equipment to integrate the various stations of the PowerGuard assembly process into a seamless production line with an even throughput. Experience indicated that some additional production stations were necessary to ensure fully automated conveyance of the feedstock. These stations were to be fully integrated with the conveyor assembly and were to include these processes: loading boards into the conveyor line, cutting boards to proper dimensions prior to routing, scoring board surfaces for improved adhesion of the coating under the spacers, and separating boards following the coating station.

Expected results were continuous, station-to-station operation, and a 50 percent reduction in operators.

#### 2.3.7.2. Results

PowerLight has implemented a continuous, station-to-station operation. The number of operators has been reduced from 4 full time workers to one half time worker, which represents an 87 percent reduction in labor.

#### 2.3.7.3. Discussion

The machinery implemented under this task was designed as an integrated system. All of the machinery is controlled by one programmable logic controller (PLC), and a series of sensors track the position of the material as it is processed to coordinate the movement of the machinery. In part due to improvements discussed in this section as well as improvements to other parts of the production line, PowerLight has been able to produce as many as 440 tiles in a single shift, which includes preparing the line prior to production and cleaning up after production.

The board stock is delivered to the PowerLight factory in large stacks of either 48” x 96” boards or 128” x 50.5” boards. A stack of boards is set on the input conveyor for the panel loader. The input conveyor has two rows of rollers and a central powered belt. An optical sensor in the middle of the input conveyor senses the presence of a stack. The belt is turned on by the PLC to move the stack forward. A second sensor is triggered when the stack is close enough to the de-palletizing lift, and the belt is turned off. A second stack of boards can then be loaded onto the input conveyor to be automatically moved into position when the first stack is depleted.

Four vacuum cups on an articulated arm pick up the top board on the stack (Figure 14). The arm then moves over the production line and down to a drop position. The board is then dropped through two sloped guides onto a belt. The arm then returns to the position to pick up a new board from the stack. The board that has been dropped onto the belt is moved forward toward two saw stations.

**Figure 147. De-palletizing Station for XPS Stock**

The first saw station is the rip saw, which cuts the board to the required width. The saw is stationary and cuts the board as the board moves past it. Scrap is dropped down onto a set of rollers slightly below the level of the main conveyor where it gathers until an operator clears it away. The position of the rip saw can be adjusted via a hand wheel attached to a screw. The position is adjusted, depending on what size PowerGuard tile is being manufactured, and held in place by a clamp.

The board then moves to the cross cut saw, which cuts the board into shorter sections for the router to cut the tongue and groove profile.

The cut boards are next delivered to the tongue and groove router. An operator loads the boards onto the router, which cuts the tongue and groove profile into the boards. They are then ready for the coating process.

### 2.3.8. Task 21.0: PowerCurb Housing

#### 2.3.8.1. Objectives

Under this task, PowerLight was to evaluate in-house capability to fabricate the PowerCurb housings while reducing cost per linear foot of curb and increasing quality assurance and quality control (QA / QC). Results were to include an assessment of unit cost and a 50 percent labor reduction.

#### 2.3.8.2. Results

Three methods were assessed based on cost goals; see discussion. None of the methods proved to be cost effective at our current production volumes. We are pursuing the molding method in anticipation of larger production volumes in the future.

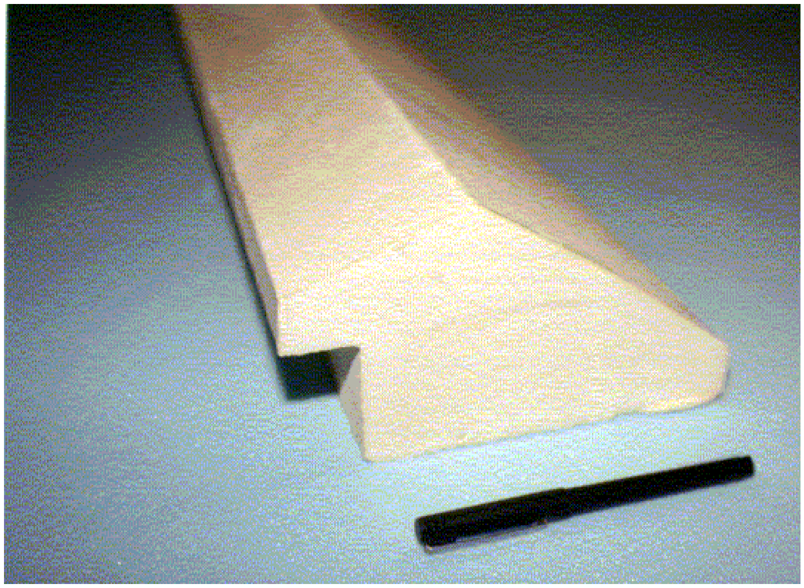

**Figure 158. Molded Curb**

#### 2.3.8.3. Discussion

Several different methods of manufacturing curbs have been investigated. The possible methods considered were molding, extruding, and stamping. Each method involves certain tradeoffs.

Initially, research indicated that molding would be the most financially and qualitatively beneficial method. Two methods of molding curbs were investigated. Both methods involved fabricating plastic molds that would be filled with a modified cement mixture. One method involved using a durable mold, which would be used several times. The curbs would be taken out after they had cured. The other method used a much thinner mold, which would become the outside surface of the curb. Final costs were similar for each method.

After initial tooling outlays, molding could produce curbs at the target price per foot. However, engineers determined that the cost of dedicating the large amount of factory space needed for curing would push curb costs above target.

Extruding appears to be the lowest cost method, though it has turned out to be problematic in practice. Prototype equipment was tested in the PowerLight facility. It was set up on a conveyor so that the extruded material would move along the conveyor and could then be cut to length and moved to curing storage.

Tooling costs for extruding are much less than for molding. However, as with molding, full production would require setting up an assembly line and would likewise require a large amount of dedicated factory space. Costs, while lower than molding, were still at the top of the target range.

In addition, extruding proved to be difficult to control to the required tolerances. The consistency of the mix going into the extruding machine had to be controlled very carefully or the material would be too wet and would slump or it would be too dry and would crumble when cut to length. It was also difficult to produce a curb sufficiently straight without complicated fixturing. Additionally, the surface of the extrusion needed to be finished by hand, and it was easy to deform the extrusion during this process. Even with the mix controlled very carefully, the cuts were never clean and always had to be dressed by hand. This increased the labor requirement significantly and slowed down the process, making the actual costs much higher.

The final method investigated was stamping. Concrete stamping is commonly used for making cinder blocks and patio bricks. Large numbers of identical parts can be turned out very quickly. Stamped parts are often used in outdoor applications, so it seemed that they should be well suited to the needs of PowerGuard curbs. Stamping machines are very large and generally have very high capacities. A single stamping machine could produce enough curb material for PowerLight for a typical year's production in 9 to 10 hours. Cost outlays for this method would include the fabrication of a fairly expensive mold. However, this is the one method with the potential to bring the cost of the curbs comfortably within PowerLight's target range.

Further analysis, however, regarding curb longevity, showed that while molding and extruding yielded curbs with very good freeze / thaw resistance, the stamping process yielded curbs that performed much more poorly in freeze / thaw tests. We believe that the application of a coating material would improve the life expectancy of stamped curbs, but this would raise the cost above the target range. Uncoated stamped curbs could be used if they were replaced every ten years, but this raises the long-term curb cost.

After substantial research, engineers have determined that the two possible choices at this time are molding or stamping. Molding involves committing considerable resources and factory space to the manufacturing of curbs. Stamping involves considerable setup expense and requires further experimentation to find a mixture with sufficient resistance to freeze / thaw damage. Though it seemed that a practical solution had been found for a new curb design at lower cost, the subsequent investigation of manufacturing methods showed that further research is needed to identify a new curb design to satisfy cost needs and to identify a suitable manufacturing method for that design. It is PowerLight's intention to continue this research beyond the scope of this phase of this project.

### 2.3.9. Task 22.0: PowerBus™ Harness Assembly

#### 2.3.9.1. Objectives

Under this task, PowerLight was to assess options to lower the cost of assembling wire harnesses that connect AC PowerGuard tiles in parallel and high-voltage DC tiles in parallel. PowerLight was to select a vendor to develop a mold to fully encapsulate and environmentally seal the splice, perform environmental exposure testing of sample harnesses, and evaluate harness performance in system installations. The revised design was expected to reduce unit costs by 80 to 90 percent and was to be submitted to UL for listing.

#### 2.3.9.2. Results

The new design has passed all functional and life cycle testing and has been submitted to UL for listing. When all parts of PowerGuard systems are UL listed, permitting of new installations will be simplified, which will help cut costs.

#### 2.3.9.3. Discussion

PowerLight researched many different methods to make the T-connection for this assembly. A spliced connection with an overmolded insulator showed promise at first but failed life cycle testing. It also proved difficult to find a UL listed or recognized material for overmolding that would bond with the insulation material of the wire.

The final design uses an ultrasonically welded connection with a heat-shrink, insulating jacket. The complete harness consists of a trunk wire with several branch wires extending off at even intervals. Connectors are installed on the ends of the trunk wire as well as the end of each branch wire. Typically the connectors are installed in PowerLight’s factory, but this can also be done on-site if necessary. The connectors are the same as those used in the standard PowerGuard tiles, so the parallel wiring connections can be made on-site just like regular PowerGuard array installations. Provisions have also been added for inserting a diode in each branch wire when necessary.

This new design was developed both to satisfy UL requirements and to be compatible with the connected wire so that this connection will comply with National Electric Code (NEC) requirements.

### 2.3.10. Task 23.0: Modular Source Circuit Combining Circuitry (SCCC)

#### 2.3.10.1. Objectives

Under this task, PowerLight was to design an integrated circuit board to replace the discrete components of PowerLight’s array J-box; a modular scheme for connecting the array J-boxes to system combiner boxes in the field; and a system combiner box with integrated circuitry components.

The result was to be the development and assessment of a newly standardized Source Circuit Combining Circuitry scheme with integrated circuitry, modularity with system size, and integrated components. Costs were to be reduced by 30-50 percent and installation time of SCCC components reduced up to 50 percent for larger systems.

#### 2.3.10.2. Results

The revised design has cut material costs by 60 percent and labor costs by 80 percent. Installation time of SCCC components has been reduced by 90 percent.

#### 2.3.10.3. Discussion

The revised modular SCCC design incorporates two boxes. A terminal box on the roof provides a weatherproof transition from outdoor grade wire to less expensive indoor grade wire. Wire gage can be upgraded at this point to accommodate voltage drop considerations. A combiner box near the inverter provides over-current protection and parallels strings prior to entry into the inverter DC disconnect.

Because a typical 100-kW installation now requires three boxes instead of twelve, the savings in labor and materials are considerable without applying integrated circuit technology (originally a task objective). Also, with the simplification of the components in the boxes, an integrated circuit board is not only unnecessary (since diodes have been eliminated) but would be much more costly to develop. Each pair of boxes is custom sized for each job, with modular parts. The advantages of the current SCCC design are clear:

- Material cost savings of 60 percent and labor cost savings of 80 percent have been realized by reducing the number of electrical boxes, placing the DC circuit surge protector in the inverter, and removing blocking diodes;
- The strings are clearly marked in the combiner box and are easily accessible for diagnostics and voltage checks. The box is near the inverter, which greatly aids troubleshooting. It is possible to measure open circuit voltage (Voc) and operating current for every string of a 100-kW array in 15 minutes.
- The terminal box on the roof significantly cuts down on labor time, since the array wires terminate on the roof. The continuing wires are pulled through the rooftop conduit in a bundle.
- The terminal box allows the transition from outdoor-rated RHW wire to less expensive THHN wire, and provides the opportunity to use larger gage wire, if the voltage drop to the inverter is too high with the 12 gage harness.
- The terminal box provides a weather-tight method of getting wires from outside to inside the building and provides a transition for conduit attachment.
- Access to boxes does not require disassembly of the PowerCurb, which reduces diagnostic and maintenance labor time significantly.
- Boxes can be assembled in the shop, with wire tie-downs pre-installed to cut down on field assembly time.
- More than one rooftop terminal box can be used for arrays split up around the roof.

### 2.3.11. Task 24.0: Thin Film Tile Packaging

#### 2.3.11.1. Objectives

Under this task, PowerLight was to deliver a prototype a-Si tile for testing at NREL or Sandia National Laboratories (SNL). The tile design was to achieve a 10-20 percent reduction in board fabrication costs, while maintaining a 30-year design life and not exceeding laminate temperatures of 90°C.

**Figure 16. Thin-Film PowerGuard Array**

### 2.3.11.2. Results

All objectives were met. Cost savings exceeded 30 percent. The tile has a 30-year design life. It does not exceed laminate temperatures of 90°C.

### 2.3.11.3. Discussion

A thin-film module with a 1” spacer was shipped to NREL for testing on May 1, 2000. The a-Si tile may be fabricated using one of two preferred thin-film laminates.

The a-Si tile is constructed in the same way as the PowerGuard tile, except that 1” tall stand-offs (spacers) are used in the place of spacers that are typically 2” or 3”. Therefore, cost reductions already achieved for the PowerGuard tile are identical for the a-Si tile. During Phase I, PowerLight documented savings in PowerGuard tile fabrication of 30 percent or more. Additionally, the reduction in spacer height results in material savings as well as shipping savings due to higher shipping density.

Accelerated life testing already conducted on the PowerGuard tile suggests that it can withstand 30 years or more in a rooftop environment. This testing has been conducted by UL, Arizona State University, Colorado State University (wind tunnel), the manufacturer of the PowerGuard adhesive, and internally by PowerLight. Testing has focused on the bond strength of the spacer attachments, resistance of the coating to freeze-thaw, and wind resistance of the PowerGuard arrays. While the a-Si tile design results in slightly higher PV operating temperatures, field results show that these temperatures remain below 90°C. Because prior accelerated life testing on PowerGuard components included temperature cycling between 90°C and –40°C with no performance degradation, the increased PV temperature should not reduce the life of the a-Si tile. In addition, our measured operating parameters are within the operating range guaranteed by the manufacturer; thus no decline in lifetime is anticipated.

A series of field tests in July and October, 1999, in Sacramento, CA, showed that a spacer height of 1” resulted in peak PV operating temperatures as high as 77°C under open circuit conditions, when the ambient temperature was over 33°C. However, further research is being conducted to monitor PV and tile temperatures in various ambient conditions. An array of 1” a-Si tiles has been installed for long term monitoring on the PowerLight factory where ambient temperatures greater than 33°C are expected.

### 2.3.12. Task 25.0 PowerGuard Field Assembly

#### 2.3.12.1. Objectives

Under this task, PowerLight was to design and test a new mounting system to reduce manufacturing costs and to make field installations easier.

#### 2.3.12.2. Results

A PowerGuard tile suitable for field assembly has been designed. It has the advantage of lending itself to a sloped PV laminate which will increase energy capture.

#### 2.3.12.3. Discussion

The final design is largely constructed of sheet metal. The sheet metal is stamped out into the required shape and then shipped flat to the PowerLight factory. Cost is reduced by having the materials shipped flat to the factory. The design consists of just four parts in addition to the PV laminate and the coated backerboard. Three metal strips are bent and attached to the coated board. A wind deflector with support legs which support the PV laminate at the top edge of the slope is attached to the PV laminate and then can be snapped into the three metal base strips.

Figure 17 shows the initial prototype, with the complete assembly popped up into a sloped position to maximize energy capture.

**Figure 17. Prototype PowerGuard Field Assembly Tile**

### 2.3.13. Task 26.0 Environment, Health, and Safety

#### 2.3.13.1. Objectives

Under this task, PowerLight was to incorporate applicable Federal and State Regulations into equipment design, operations, worker safety programs, installation manuals, Operations and Maintenance (O&M) manuals, and training programs. PowerLight was to ensure compliance with all applicable safety and environmental regulations.

#### 2.3.13.2. Results

Federal and State regulations governing the manufacture, installation and operation of PowerGuard PV roof tiles have been reviewed since the beginning of 1998. An assessment was conducted to identify those regulations within Federal and State Codes that apply to PowerLight's activities and therefore are relevant to process and equipment design.

PowerLight has ensured that all pertinent environmental and OSHA regulations are being met by initially reviewing these guidelines and incorporating them into equipment design, and by employing an OSHA representative and an environmental consultant to inspect the facility. In addition to these actions, PowerLight has also ensured worker safety by updating the installation and O&M manuals to incorporate the latest design and safety practices. These manuals and the initial training programs that PowerLight has begun will ensure that these systems are installed in a manner compliant with all OSHA and environmental regulations.

In addition, PowerLight has made a concerted effort to recycle its manufacturing by-products and has made the reduction of wastes a manufacturing priority. For instance, 95 percent of foam waste is recycled.

### 2.3.14. Task 27.0: Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

#### 2.3.14.1. Objectives

Under this subtask, PowerLight was to complete additional wind tunnel studies on PowerGuard RT systems; compile data from wind tunnel studies on PowerGuard RT systems into a final report; analyze failure data for PowerGuard RT systems and create final wind design tables; and create wind design tables for European and Japanese markets.

Wind tunnel tests are used to fully characterize PowerGuard's unique aerodynamic performance.

#### 2.3.14.2. Results

Pressure tapping was conducted on roof models used in this study to draw comparisons to published data and validate the entire study. This effort was successful in that non-intuitive trends in some of the failure data were explained through the pressure measurements. Peer reviews of the pressure data and failure measurements were positive.

The effects of water on the rooftop, a more accurate model of the RT curb, and extended securement options for RT arrays were studied and included in the creation of final wind tables.

A table was created for corrugated metal roofing, as this type of roofing is commonly used on commercial buildings in Japan.

Full-scale testing of sloped PowerGuard in high winds revealed that the deflector panel experienced large oscillations and needed structural reinforcement. This was accomplished by incorporating a support mechanism at the center of the PV and deflector panel.

Wind testing results were used to establish wind tables, which are used by the PowerLight sales staff to determine the best PowerGuard system for a specific roof in a specific location. This reduces the amount of repetitive engineering work for each PowerGuard installation, thus reducing system cost.

### 2.3.15. Task 28.0: Underwriters Laboratories (UL)


**Figure 18. PowerGuard UL Label**

#### 2.3.15.1. Objectives

Under this subtask, PowerLight was to continue working with UL to expand PowerGuard's original UL listing, add additional modules to the PowerGuard system, complete additional fire testing, and add components to PowerGuard's Accessory File.

#### 2.3.15.2. Results

PowerGuard's UL listing was expanded to include four new modules. Additional fire testing was completed. During this period, PowerLight began the process of updating the PowerGuard Accessory file to reflect current practices.

#### 2.3.15.3. Discussion

PowerGuard was originally listed with only the one module. In November 1999, PowerLight submitted an application to list three additional module assemblies – each module from a different manufacturer – as components in the PowerGuard mounting system.

To list these tiles, UL requires that the frameless module be certified as a UL recognized component. Then PowerLight is required to follow the re-test requirements in UL 1703 that are applicable to mounting structures. These tests include accelerated aging testing, fire testing, humidity testing, mechanical load, temperature cycling, and a voltage current and power test.

Since these tests were completed with the original listing of PowerGuard, UL only required additional mechanical load testing to be completed. Additionally, since these modules are dimensionally similar, UL required only one of the three to be tested and its similarity to the other two qualified.

In December 1999, PowerLight sent a PowerGuard tile with one of the three modules to be listed to UL to undergo mechanical load testing. It withstood 293psf uplift load, which more than surpassed the 45psf required by UL 1703.

In January 2000, PowerLight submitted an application to list an a-Si module with the PowerGuard mounting system. Since this module's backing is glass and not Tedlar, UL required additional adhesive testing. In February, PowerLight submitted samples of XPS adhered to glass with its preferred adhesive to undergo testing. This testing was successful, and in March 2000 this module was listed with the PowerGuard system.

As most modules have only been tested to Class C fire requirements, when PowerGuard was originally listed under Phase I it was tested to these requirements as well. However, during October 1999, PowerLight conducted extensive internal testing, to Class B and A requirements. Through this testing PowerLight found that the concrete coating allowed the product to withstand a Class B burning brand without exposing the roof deck.

In November 1999, PowerLight submitted a PowerGuard tile incorporating a preferred module for Class B fire testing at UL. This testing was successful, and since this module is intrinsically a Class C module, UL listed all PowerGuard tiles that incorporate modules with a Class C fire rating as Class B PowerGuard tiles.

At the same time, PowerLight submitted an additional PowerGuard tile for Class A fire testing, as it incorporated a module that already holds a Class A fire rating. This testing was successful and in December 1999, UL listed this tile as a Class A PowerGuard tile.

When PowerGuard was originally listed under Phase I, PowerLight listed three accessories to be used with PowerGuard. These included PowerBox™, PowerCurb, and PowerBus. In the fall of 1999, PowerLight received a quote from UL to submit an updated PowerCurb to the PowerGuard Accessory File to reflect current design practices.

### 2.3.16. Task 29.0: International Certifications

#### 2.3.16.1. Objectives

Under this subtask, PowerLight was to continue working with the International Compliance Services (ICS) department of UL and other organizations to determine the standards applicable in the European Union (EU) and Japan. In this phase, PowerLight focused on the requirements of the CE Mark, International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE) standards, and the specific requirements of Germany and Japan.

#### 2.3.16.2. Results

PowerLight has met all EU requirements to apply the CE Mark, required for any product exported to Europe. In addition, all relevant IEC and IEEE testing has been completed.

#### 2.3.16.3. Discussion

Germany and Japan have favorable markets for PowerGuard, and so under Phase II PowerLight thoroughly researched the specific requirements of these countries.

Germany: In addition to IEC and IEEE standards, Germany also requires PV systems to have the TUV safety mark and conform to fire standards outlined by the Otto-Graf-Institute, Research and Testing Establishment for Building and Construction Products (FMPA). In August of 2000, PowerLight submitted samples to FMPA for B2 fire testing. PowerLight has received certification from the Otto-Graf-Institute for PowerGuard based on DIN 4102 part 1, building materials class B2.

Japan: A license partner in Japan was identified and has acquired appropriate building and fire codes through the Japanese Ministry of Construction. These codes were being updated to conform to IEC requirements. The new standards were published in January 2001. At that time, the Japanese Ministry of Construction specified that they would recognize IEC certification until 2003.

### 2.3.17. Task 30.0: Integrated Design Software

#### 2.3.17.1. Objectives

Under this task, PowerLight was to simplify the physical and electrical design of PowerGuard systems by developing custom Integrated Design Software based on an AutoDesk® program called Actrix® Technical 2000. This software would easily incorporate drawing specifications into MS Excel® spreadsheets, which allow a Bill of Materials (BOM), permit drawings, and quotations to be generated in an expeditious manner.

This software was to automate the design process, the creation of the BOM, and quotation packages based on the array layout and electrical drawings generated by the user; allow both experienced and inexperienced AutoCAD users to create an array layout and electrical drawings; and allow a user to move drawings between AutoCAD and the software.

#### 2.3.17.2. Results

PowerLight has adapted off-the-shelf integrated design software to meet all objectives.

#### 2.3.17.3. Discussion

After receiving quotes from qualified consultants, PowerLight chose to use an off-the-shelf software, Actrix Technical 2000. PowerLight chose Actrix because it was developed by AutoDesk and is therefore inherently similar to AutoCAD. Actrix also has many key features, including the ability to create active shapes. It can also be customized by Visual Basic® for Applications to create a user-friendly, automated interface.

Once Actrix was selected, PowerLight worked with the subcontractor to create three templates (rooftop array layout, electrical schematic, and electrical room elevation) in which a user could create a drawing. Figure 19, Figure 20, and Figure 21 show these templates and a sample drawing created in Actrix using the template.

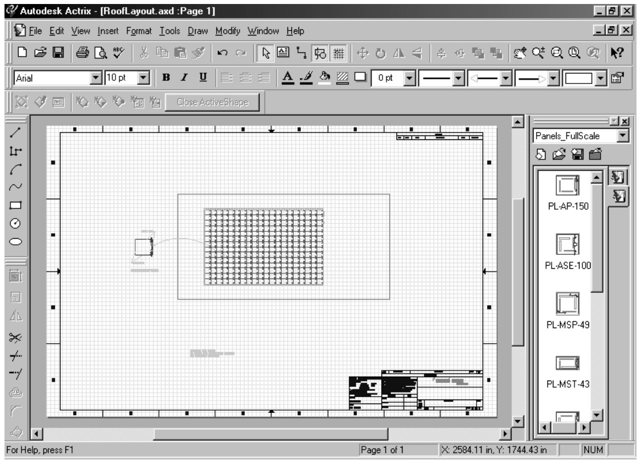


**Figure 19. Sample Rooftop Array Layout Created in Actrix Technical 2000**

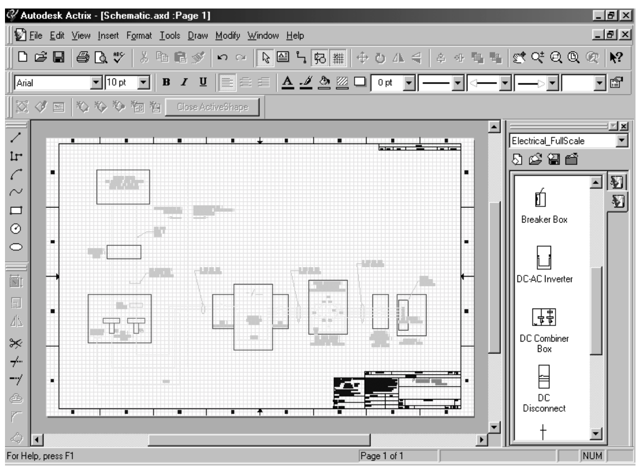


**Figure 20. Sample Electrical Schematic Drawing Created in Actrix Technical 2000**

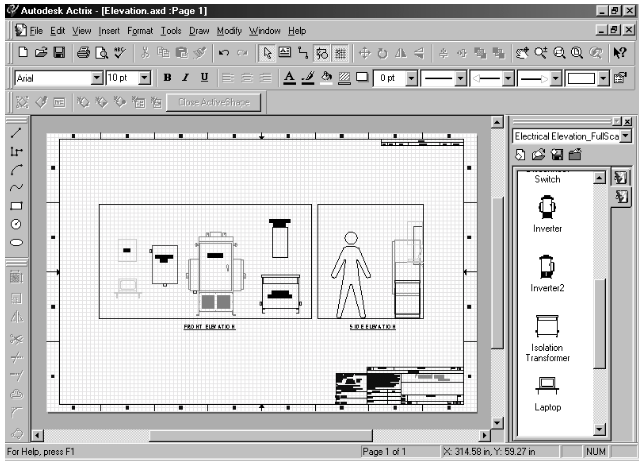


**Figure 21. Sample Electrical Room Layout and Elevation Drawing Created in Actrix**

In each template, the active shapes are shown to the right of the drawing field. Each shape has an associated cost, power, and backerboard dimension. These properties can be edited and added to over time as the parameters of the selected laminate tile are modified. The user places the shapes into the drawing field. Actrix can then generate a property report or bill of materials (BOM), incorporating the chosen shapes' properties, in a tab delimited (.txt), comma separated (.csv), or Microsoft Excel (.xls) format. The property report wizard is similar to an Excel Chart wizard, in that it allows users to choose the fields to be included in the report. These reports can eventually be linked to a Material Requirements Planning (MRP) system.

Although Actrix has some limitations, PowerLight has found it to be a cost-effective design tool. The customized software allows both experienced and inexperienced AutoCAD users to design a PowerGuard system with ease. This software will save many hours of engineering and marketing time by automating the design process, and creation of the BOM and quotation package. As PowerLight quotes and designs more and more projects, this will be increasingly important.

### 2.3.18. Task 31.0: PowerGuard System Packages

#### 2.3.18.1. Objectives

Under this task, PowerLight was to evaluate its systems and new products to redefine PowerGuard system packages based on the most economical modular increments. Because of the variety of fixed costs involved in designing, permitting, and installing, the smaller the project, the higher the per-watt cost of a PowerGuard installation. For relatively straightforward installations, substantial cost savings can be realized if some of the processes associated with fixed costs are standardized.

#### 2.3.18.2. Results

PowerLight has created a series of system packages based on economical modular increments. Additionally, three standard size systems have been listed with the federal government's General Services Administration (GSA). PowerLight has negotiated pricing with GSA for 100-kW, 250-kW, and 500-kW PowerGuard systems.

### 2.3.18.3. Discussion

PowerLight has created a series of system packages based on economical modular increments. An installation manual was created for the specified systems and was distributed to qualified Value Added Resellers (VARs). When this was originally done, the standard systems were sized at 4-kW, 10-kW, 25-kW, and 100-kW. Since then, PowerLight has focused on larger average system sizes. Consequently, the list of standard system sizes has been expanded to include systems up to 500-kW.

## 2.3.19. Task 32.0: Assessment of Commercial Demonstrations

### 2.3.19.1. Objectives

Under this task, PowerLight was to assess commercial demonstration projects in order to evaluate system performance, review cost savings, and assess the effectiveness of changes made during Phase II of this project.

### 2.3.19.2. Results

PowerLight compared performance and cost of projects manufactured before Phase II with projects manufactured and installed after Phase II. System performance has not been compromised, and the quality (for example, fit and finish) has improved. Overall manufacturing costs were reduced 57 percent; an additional 74 percent reduction in materials costs was realized during installation. Labor requirements have been reduced, as demonstrated in batch production runs. For example: for a pre-phase II project, it took 6 weeks and 6 workers to manufacture 350 boards. For a post-phase II project, it took 2 days and 8 workers to manufacture 500 boards.

### 2.3.19.3. Discussion

This report has detailed a number of manufacturing improvements. The following are additional PowerGuard manufacturing and installation assessments of project installations during this period that incorporated advancements made as a result of this program. The aspects considered were: palletizing, roof preparation, handling of materials, materials lift, PowerGuard tile manufacturing router and tile alignment, RT Curb corner design, thin-film parallel wiring connectors, and DC electrical equipment consolidation.

***Palletizing with the Stretch Wrapping Sidewinder Machine***

With the addition of the stretch wrapping Sidewinder machine PowerLight has been able to improve packaging by better securing PowerGuard tiles to pallets and to decrease stretch wrapping labor costs with increased wrapping efficiency when compared to previous hand held plastic wrapping tools. The risk of breakage during shipment has decreased because materials are better stabilized when compared to hand wrapped pallets. The stretch wrapping Sidewinder machine has also eliminated onsite re-wrapping of hand wrapped pallets prior to craning to the roof. This in turn has decreased onsite labor costs.

**Figure 22. PowerGuard Tiles Being Lifted to Building Roof**

### *Roof Preparation & Crane Lift*

When PowerGuard tile pallets are lifted, a protective 2” polystyrene board larger than the module needs to be placed on the top to prevent the pressure of the lifting straps from breaking the top module. The angle of the lifting straps from the edge of the top module to the lifting ball must not be less than 60 degrees to prevent added pressure to the top modules.

### *Router Cutting Improvements*

Router improvements on the manufacturing line have greatly improved PowerGuard tile alignment. This has made the installation of the PowerGuard tiles easier, which in turn has decreased installation time. Improved alignment also has aesthetic benefits. When boards are identical in width, length, and height the mortar edges fit together tightly creating perfect lines throughout the PowerGuard system.

### *RT Curb Corner Design*

With the design of square box RT Curb Corners, the installation of the RT Curb has improved. It is easier to install the corners than to make miter cuts on the RT Curb. The RT Curb Corners are also forgiving in that they minimize the effect of uneven roofs on the RT Curb. The RT Curb Corners are slightly taller than the RT Curb, allowing height differences of the RT Curb to blend into the RT Curb Corner.

*Parallel Wiring of Thin-Film Strings on the Roof*

On the PowerLight project, parallel wiring harnesses were used with thin-film modules on the roof. This design decreased the number of wire runs from the array to the terminal box and from the terminal box to the DC-fused Combiner box. With this decrease in wires, these two boxes were designed to a smaller size, which in turn allowed consolidation of DC electrical equipment. Without parallel wiring, installers would need to fabricate, in the field, 72 wire runs from the array to the inverter. With parallel wiring, only 16 such “home runs” were required. This resulted in a 74 percent cost reduction in materials and field labor.

*DC Electrical Equipment Consolidation*

With a smaller terminal box, it is possible to integrate DC electrical equipment into the RT Curb, eliminating the costs of additional mounting hardware. PowerLight has reduced costs by purchasing smaller, less expensive electrical boxes and decreasing the purchase quantity of electrical components used for internal wiring. A smaller DC-fused Combiner box also makes it easier to locate mounting areas in electrical rooms.

## 2.4. PHASE III (of III)

### 2.4.1. Task 33.0: Optimized Retooling for Capacity Expansion

#### 2.4.1.1. Objectives

Under this task, PowerLight was to work with selected U.S. PV partner(s) to design any required modifications or retooling of their standard PV laminate manufacturing plant to expand production capacity for PowerGuard products. The result was to be a plan for expansion of U.S. PV laminate manufacturing capacity for application with the PowerGuard product.

#### 2.4.1.2. Results

PowerLight produced a complete set of PowerGuard PV-to-Backerboard assembly tooling and installed it at the end of the laminate production line of a U.S. PV manufacturer. The annual output of the PV laminate production line and the PowerGuard assembly equipment is 2.5-MW.

#### 2.4.1.3. Discussion

In September 2000, PowerLight reached a purchasing agreement with a U.S. PV manufacturer for 1.4-MW of laminates within the next year. This agreement required the PV manufacturer to increase capacity by 2-MW in order to deliver this quantity. PowerLight fabricated equipment to enable final assembly of PowerGuard tiles to be done at the factory of the PV laminate manufacturer.

However, after this agreement was made, the PV laminate manufacturer experienced product problems that it has yet to overcome. This has prevented the planned expansion. More recently, PowerLight reached an agreement with a different U.S. PV manufacturer. This agreement involves the installation of assembly equipment at the PV manufacturer’s facility to enable final assembly of PowerGuard tiles to be done there. The PV manufacturer has rearranged its manufacturing facility in order to place the PowerGuard assembly equipment at the end of the production line. The annual output of the combined production system is expected to be 2.5-MW.

This arrangement will be advantageous for both the PV manufacturer and PowerLight. The PowerGuard production process will use the entire current production output of the PV manufacturer's facility. Assembling PowerGuard tiles in the same facility where PV laminates are manufactured will remove the packaging and shipping steps from the overall process, thus reducing cost.

The combined line was ready to start production in January 2002.

### 2.4.2. Task 34.0: Equipment/Facility Assessment

#### 2.4.2.1. Objectives

Under this task, PowerLight was to assess the performance and manufacturing improvements resulting from the retooling / expansion of the PV laminate capacity of a U.S. manufacturer as designed in the previous task, Optimized Retooling for Capacity Expansion.

#### 2.4.2.2. Results

As explained in section 2.4.1, PowerLight set up assembly equipment at the end of the PV laminate production line of a U.S. PV manufacturer. This production line will produce 2.5-MW annually specifically for use in PowerGuard tiles. This increase did not require any special equipment except for PowerGuard assembly equipment, which PowerLight sent to the factory of the PV manufacturer.

The PV manufacturer has continued to produce PV for use in PowerGuard tiles as specified in the purchase agreement. The PV laminates being produced meet PowerLight's specifications and will continue to be assembled into PowerGuard tiles.

### 2.4.3. Task 35.0: Wind Testing: Computational Fluid Dynamics (CFD), Wind Tunnels

#### 2.4.3.1. Objectives

Under this task, PowerLight was to investigate installations on roofs with mechanically attached membranes under varying wind conditions. Installation of PowerGuard on mechanically attached roof membranes requires understanding if and how such roofs must retrofitted so that the installed systems meet performance requirements. To accomplish this, PowerLight worked with subcontractors to test the behavior of PowerGuard tiles on a roof simulator with a mechanically attached membrane under varying wind conditions.

#### 2.4.3.2. Results

The wind stability of PowerGuard tiles on fully adhered roofing systems, and single ply roofing systems with air barriers, has been proven through wind tunnel studies.

#### 2.4.3.3. Discussion

Mechanically attached, single ply membrane systems without air barriers present a unique challenge for PowerGuard systems, because these roofing systems have the potential to balloon, or billow, in relatively low winds (5psf uplift pressure). Such billowing could displace the loose-laid roofing pavers.

Models of PowerGuard tiles were installed on a test apparatus that simulated the billowing of a mechanically attached TPO membrane. The test apparatus consisted of an enclosed test bed with a mechanically attached roof system on the top surface. This set up can be pressurized internally with various pressures. Deflections of the membrane and tile system were measured with and without PowerGuard tiles installed on top of them, using surveying equipment.

The data were analyzed so that the pressures that were used could be translated into typical field conditions representing various building heights, rooftop location, and surrounding terrain. If acceptable deflections were obtained in the experiment for the pressures that could be experienced in the field, then the recommended membrane securement can safely be used with the PowerGuard system.

It was determined in this experiment that additional membrane securement with batten bars placed under the array area in a specific pattern would limit deflections to allowable levels for most PowerGuard installations.

### 2.4.4. Task 36.0: Underwriters Laboratories Listing (UL)

#### 2.4.4.1. Objectives

Under this subtask, PowerLight submitted modified PowerGuard® products to UL for listing. This is the final phase of UL listing for this project.

#### 2.4.4.2. Results

***PowerGuard tiles***

In the course of the PIER contract, seventeen PowerGuard tiles, using PV modules from different manufacturers, have been listed by UL. PowerGuard's original listing was for the PL-MSX-120 using the Solarex MSX-120 module. Table 6 shows all UL listed PowerGuard tiles to date.

**Table 6. PowerGuard Tiles**

| PowerGuard Tile | PV Module |
|---|---|
| **PL-MSX-120** | BP Solarex MSX-120 |
| **PL-AP130** | Astropower AP130 |
| **PL-AP120L** | Astropower AP120L |
| **PL-AP75** | Astropower AP75 |
| **PL-AP75 Double Module** | Astropower AP75 |
| **PL-ASE100** | ASE Americas ASE100 |
| **PL-SP-75** | Siemens SP-75 |
| **PL-SP-75 Double Module** | Siemens SP-75 |
| **PL-SP-135** | Siemens SP-135 |
| **PL-SP-150** | Siemens SP-150 |
| **PL-SP-150-24L** | Siemens SP-150-24L |
| **PL-FS-415** | First Solar 415 |
| **PL-PW750** | PhotoWatt PW750 |
| **PL-BP-2150S** | BP Solarex BP-2150S |
| **PL-BP-TF-80L** | BP Solarex TF-80L |
| **PL-MST-43** | BP Solarex MST-43 |
| **PL-MST-43 (Alternate construction)** | BP Solarex MST-43 |

***Accessories***

PowerCurb, for both RT and LG PowerGuard systems, was listed as an addition to the PowerGuard Accessory File.

***T-harness***

Internal testing was completed for the parallel connector harness, or T-harness, in June, and samples were sent to NREL for accelerated life testing. Samples were then submitted to UL for listing.

***Combiner boxes***

PowerLight engineers are currently designing five standard combiner boxes, each covering a range of voltages, to be used for all installations. It is highly likely that these boxes will be fabricated by an outside vendor. When specifications are complete, samples will be fabricated and submitted to UL for design review.

### 2.4.5. Task 37.0: International Conference of Building Officials Certification

#### 2.4.5.1. Objectives

Under this subtask, PowerLight was to work to obtain International Conference of Building Officials (ICBO) Certification. The Uniform Building Code (UBC) is used by over 2500 building departments nationwide and is by far the predominant code standard. ICBO certified products are reported to every building department on an annual basis informing local officials of compliance. ICBO certification would reduce costs by streamlining permitting processes, which can be time-consuming.

#### 2.4.5.2. Results

PowerLight worked with officials from the ICBO - Evaluation Service (ES) to determine which acceptance criteria apply to PowerGuard. Based on these discussions, PowerLight submitted an application for evaluation.

ICBO-ES reviewed existing test data on wind and fire for PowerGuard and has identified further testing that is required, specifically more fire tests and weatherability tests. Additional tasks include creating a quality control manual according to ICBO acceptance criteria and having it approved by a certified agency; formatting the wind test results for inclusion with the ICBO evaluation; soliciting documentation from Dow Corporation on the foam we use; providing information about the mortar coating used on PowerGuard and design considerations for drainage; and providing laboratory accreditation for the wind test. To simplify the requirements, the Evaluation Report will include PowerGuard RT only, and not PowerGuard LG. The costs and time to collect the information is currently being evaluated against the benefits of completing the ICBO Evaluation. In the mean time, PowerLight continues to proceed.

### 2.4.6. Task 38.0: Product Installation Information

#### 2.4.6.1. Objectives

Under this task, PowerLight was to develop product installation information for the installation of PowerGuard systems.

### 2.4.6.2. Results

An installation manual was developed and has been distributed to all Value Added Resellers (VARs) and certified installers. It contains sections on system description and safety, siting and roof preparation, system parts, tile installation, RT curb installation, electrical intertie, system start-up, and trouble-shooting and repair. The manual also provides the specifications for UL listed PowerGuard tiles.

## 2.4.7. Task 39.0: Assessment of Improvements in Commercial Demonstrations

### 2.4.7.1. Objectives

Under this task, PowerLight was to assess the results of a commercial demonstration. PowerLight was to evaluate the performance of the systems, review the cost savings, and assess effectiveness of changes made during Phase III.

### 2.4.7.2. Results

The results of the three commercial demonstration assessments completed over the course of this contract show that as a result of this work, the cost of a PowerGuard system has been reduced by 38 percent, as demonstrated above, while the Balance of System costs for PowerGuard systems including installation costs have been reduced by 68 percent. Production rate has gone from 100 tiles per shift to over 500 tiles per shift. Quality has been improved at the same time.

### 2.4.7.3. Discussion

The commercial demonstration projects for each phase of this PIER contract were used to compare costs and manufacturing improvements.

**Figure 23. PowerGuard 20kWp Thin-Film System**

In Phase I, PowerLight assessed a commercial demonstration project as a snapshot of the PowerGuard production process before all the improvements implemented in the course of this contract. At the end of Phase II, PowerLight assessed another commercial demonstration to gauge the effectiveness of the next wave of improvements to both process and product. Now, at the end of Phase III, PowerLight has continued to greatly reduce PowerGuard system costs while steadily improving product quality, as shown by the results of the cost assessments of the first commercial demonstration project and this latest one, completed in 2001.

At the end of Phase I, the cost of PowerGuard tiles had been reduced by 30 percent, and the production rate was more than 200 tiles per shift. At the end of Phase II, the cost of PowerGuard tiles had been reduced by 57 percent, and the production rates was more than 400 tiles per shift.

The tasks in Phase III did not focus on improvements in product and process as they were in Phases I & II. However, PowerLight has continued to bring costs down by streamlining and improving the manufacturing process. Production rates were over 500 tiles per shift during this phase. PowerLight has also continued to address quality issues by working on continuous improvement of tools and processes. Many aspects of factory operation have been improved, which has helped reduce overall costs.


**Figure 24. PowerGuard 120kWp System**

Increased demand for PowerGuard, which has been generated in part by cost reduction measures of the earlier phases of this project, has moved PowerLight into continuous production. This has allowed a shift from a temporary work force hired for each job to a full time production staff. This has improved product quality and reduced cost by reducing training needs.

After Phase I, system cost had been reduced by 15 percent compared to the first commercial demonstration project. After Phase II, system cost had been reduced by 21 percent. Now at the end of Phase III, system cost for this commercial demonstration project shows a reduction of 38 percent. This project was done with crystalline PV laminates. Based on the current cost of PowerGuard tiles for crystalline and thin-film laminates, if the project had been done with thin-film laminates, it would have cost 47 percent less than the Phase I system. However, none of the PowerGuard installations with thin-film laminates done this year was timed properly to serve as the commercial demonstration for this task.

The original project goal for this contract was to reduce system cost 46 percent, to $3.05 / watt. This target was set assuming that the cost of PV would go down as the volume of PowerGuard produced went up. Unfortunately, over the last year, the cost of PV laminates has actually gone up in many cases due to the large demand generated by the high cost of energy in the U.S. Because of this, PowerGuard system costs have not gone down as much as had been hoped. Over the course of this contract, the cost of a PowerGuard system has been reduced by 38 percent, as demonstrated above, while the Balance of System costs for PowerGuard systems including installation costs have been reduced by 68 percent.

### 2.4.8. Task 40.0: California Manufacturing Facility

#### 2.4.8.1. Objectives

Under this task, PowerLight was to identify and contract for a site for California manufacturing. The site was to be a minimum 5,000 square foot facility in which to establish PowerGuard manufacturing.

#### 2.4.8.2. Results

Notice was provided to PIER on August 1, 2000 that PowerLight had secured a manufacturing facility located at:

815 Heinz Street
Berkeley, CA  94710.

### 2.4.9. Task 41.0: Production Readiness Plan

#### 2.4.9.1. Objectives

Under this task, PowerLight was to produce and submit a production readiness plan for the California manufacturing facility.

### 2.4.9.2. Results

The following report was prepared and submitted prior to the opening of the Berkeley PowerLight manufacturing facility. This report was submitted at that time to PIER.

## 2.5. Identification of Critical Production Issues

Based upon PowerLight Corporation's experience and expectations, the following issues have been identified as critical to the successful implementation of production:

### 2.5.1. Critical Production Processes

There are two processes that are critical to the production of PowerGuard tiles: first, the coating operation and second, the routing operation. In order for PowerGuard to be a commercially viable product, these two operations must be flawless. The applied coating must be functional as well as aesthetically pleasing. It must cover the entire surface of the foam backerboard that will be exposed to the sun to protect it from degradation and give the customer the 30 year life that is desired. However, it must be smooth in texture and appearance so that all of the tiles in an array have a consistently uniform look.

The second process, routing, is what regulates the ease and uniformity with which PowerGuard tiles may be installed on a customer's roof. If the tiles are not perfectly rectangular, they will not mate properly, leaving unsightly gaps between tiles. If the tiles are not dimensionally identical, then the rows of tiles will get out of alignment producing an array of tiles that itself is not rectangular or uniform from row to row and column to column. Any lack of uniformity will make securement of the array to the roof difficult.

### 2.5.2. Critical Equipment

In addition to the router and the coating machine that will allow the above named Critical Production Processes to be successful, there are other pieces of equipment which are critical to the operation. There will be an air compressor which will supply compresses air service to run the conveyor and coating machine. If the air compressor were to fail, the production process would terminate. Also, a vacuum pump shall be utilized to operate the router. The router is unable to be operated without this critical piece of equipment. Finally, a fork lift shall be needed to receive equipment and raw materials and load finished goods. There materials and goods are too heavy and bulky to be moved by hand.

### 2.5.3. Facilities

We expect that an industrial facility of 12,000 square feet shall be required to implement production. This facility needs to be equipped with bay doors large enough to receive the largest of the raw materials (50.5" x 128" x 48" pallet of foam boards). Also, it need to be outfitted with city water (10 gpm), sewer, and 400 amps of 480volt electricity.

### 2.5.4. Manpower

Our manpower needs to run production is a single Production Manager and 15 to 20 laborer/operators. The Production Manager is a permanent PowerLight employee and shall be responsible for all production and manufacturing operations including purchasing, inventory, production planning, logistics, QA / QC, and hiring and training of operators. The operators shall be obtained from anyone of several local temporary workforce providers.

### 2.5.5. Support Systems

The critical support system shall be the team of engineers and managers in the PowerLight corporate office. When design implementation issues arise in normal production activities, timely and effective directions will be required such that production can be resumed promptly. PowerLight engineers will need to keep abreast of manufacturing activities and issues to ensure the end product being fabricated meets with their designs and expectations. In the event that technical issues arise which are unable to be answered by PowerLight staff, consultants and industry experts should be able to be contacted in a timely fashion for assistance.

## 2.6. Capacity Constraints

PowerLight has designed a manufacturing process which shall be capable of producing more than 16 MW / year of PowerGuard tiles. This expected capacity shall be affected by the following:

### 2.6.1. Machinery Design

We are designing the individual pieces of equipment to exceed a production rate equivalent to 16 MW / year of tiles. Any bottle necks in the process that may be encountered shall be addressed by redesign of equipment or implementation of additional equipment as necessary.

### 2.6.2. Facility Selection

The physical size and shape of the selected manufacturing facility will lend itself to successful implementation of our production plan. It will be of sufficient size to contain not only the manufacturing equipment, but sufficient raw materials to produce customer orders with minimal lead time. Also, there shall be enough space to store finished orders in case the customer is unable to take immediate delivery.

## 2.7. Identification of Hazardous and Non-recyclable Materials

PowerLight has used forethought in design, selecting when possible raw materials and production processes which are safe and environmentally conscious.

### 2.7.1. Hazardous Materials

The PowerGuard product minimizes the use of hazardous materials. However, some materials have been identified as potentially harmful and the necessary precautions and training shall be implemented to minimize risk. These materials are: foam dust, cement dust, adhesive (skin contact and vapors).

### 2.7.2. Non-recyclable Materials

The greatest volume of scrap from the production process shall be foam. PowerLight has arranged with a recycler to pick-up this material. Second is cardboard packaging scrap. We have arranged for a recycler for this material. Non-recyclable materials consist of foam contaminated with concrete, foam dust from the router and sawing operations, and wood packaging materials.

### 2.8. Projected Cost

PowerLight has established estimated costs per square foot of finished PowerGuard tiles, assuming a production rate of 200 or 480 tiles per 8 hour shift. This information is confidential

### 2.9. Expected Investment Threshold

PowerLight has established an expected investment threshold required to launch the PowerGuard product. This information is confidential.

### 2.10. Implementation Plan

While the manufacturing process has been designed for a capacity of 16 MW / year and 400 tiles per day production, this rate shall not be reached immediately. We expect that over the course of 2 years we will be able to implement incremental improvements to each step of the production process. By the end of the first year, our target is 200 boards per day production.

## 3.0 Conclusions and Benefits to California

### 3.1. Summary of Accomplishments

Over the course of this contract, many improvements were made to the PowerGuard product and manufacturing process. These enhancements have reduced the cost of PowerGuard installations, improved the quality and reliability of the PowerGuard product, added features to PowerGuard systems, and provided paths to new markets. A summary of the major accomplishments is listed below:

- Production rate rose from 200 tiles per 8-hour shift to more than 500 tiles per 8-hour shift.
- System cost of PowerGuard was reduced by 38 percent.
- Balance of System cost was reduced by 68 percent.
- Quality of PowerGuard was improved through the implementation of improved production tools and inspection equipment.
- A sloped PowerGuard tile design was developed.
- A comprehensive warranty was developed for PowerGuard systems.
- Extensive wind tunnel testing was used to refine the PowerGuard tile design and to develop installation criteria for a wide variety of conditions and geographical locations.
- Integrated design software was developed using an off-the-shelf platform to simplify the design of PowerGuard systems by Value-Added Resellers.
- Seventeen PowerGuard tiles, using PV modules from different manufacturers, have been listed by UL.
- PowerGuard accessories such as curbs, T-harnesses, and standardized combiner boxes have been submitted to UL for listing.

- PowerLight has applied for certification of PowerGuard by the International Conference of Building Officials (ICBO).
- All required tests have been completed to allow the use of the CE mark, allowing the sale of PowerGuard into the European Union.
- All test required by the International Electrotechnical Commission (IEC) and Institute of Electrical and Electronics Engineers (IEEE) standards have been passed.
- Modular and standardized PowerGuard system packages were developed to reduce the cost of small systems.
- An installation manual and training program was produced for installing PowerGuard systems.
- Clean-up and waste management processes have been improved leading to the recycling of almost all waste products.
- PowerLight has ensured that the production of PowerGuard conforms to National Environmental Policy Act (NEPA), Occupational Safety and Health Administration (OSHA), and all other applicable federal and state regulations.

### 3.2. Benefits to California

Increasingly, California's consumers are demanding power from clean and reliable sources. Through funding assistance from the California Energy Commission's Public Interest Energy Research Program (PIER), PowerLight Corporation is making solar power more affordable and at the same time offering additional value by extending roof lifetimes and providing buildings with added thermal insulation benefits.

Investments in solar power provide benefits to all Californians. A direct result of the State's commitment to this indigenous resource is economic development and associated jobs .

Solar-electric power systems provide a domestic source of energy that is plentiful, sustainable, and available throughout the United States. Photovoltaic (PV) systems transform clean, abundant solar energy into electricity, and are virtually maintenance free.

In the past, the main problem with generating electricity from the sun through photovoltaics has been cost. Because of projects like this one funded by the California Energy Commission, PV now makes not only environmental sense but economic sense as well. Additionally, photovoltaic generation provides an economic hedge against volatile fossil fuel prices, now and in the future.

In 2001, record prices for natural gas, which is also the nation's primary heating fuel, have translated into wholesale prices for electricity that spiked at prices as high as $1.50 per kilowatt hour. Instead of the reasonable 3.1 cents per kilowatt hour average for wholesale electricity in December of 2000 at the California / Oregon border, price in December 2001 averaged over 60 cents / kWh. Rising wholesale costs for electricity generated from a huge fleet of natural gas power plants has convinced a growing number of savvy investors that photovoltaics are affordable investments given the nation's over reliance upon natural gas.

Solar electric systems reduce operating costs by transforming clean, abundant solar energy into electricity. These on-site solar systems provide renewable power for over 30 years and offset purchases of expensive “peak” utility electricity. Solar powered installations spare the environment from thousands of tons of harmful emissions, such as nitrogen oxides, sulfur dioxide and carbon dioxide, which are major contributors to smog, acid rain and global warming. A recently installed 1.2MW PowerGuard system in Dublin, California will reduce emissions of nitrogen oxides by an estimated 24,000 pounds and carbon dioxide by 38,000 tons. Building a PV infrastructure provides insurance against the threat of global warming and climate change.

**Figure 25. PowerGuard 1.2MWp System**

Photovoltaic technology uniquely provides distributed power at the end-user level. Transmission losses are reduced or eliminated and excess generation is returned to the grid for local usage. As demand rises on transmission lines, line losses are accelerated. For example, doubling the power on the transmission line quadruples the line losses. Generating power locally avoids these costly losses.

The National Renewable Energy Laboratory underscored the benefit of installing solar PV in our nation’s urban centers in a recent report by Christy Herig, *Assessing Rooftop Solar-Electric Distributed Energy Resources for the California Local Government Commission*. Seven major outages – including one impacting San Francisco last June -- were analyzed from the perspective of the quality of the solar resource during the exact times of the power losses. In all but one of the outages, conditions for optimal solar electricity generation were above 90 percent. Interestingly, solar conditions were close to perfect (99 percent) for generating electricity from the sun on June 14th, 2000, the day 100,000 customers in San Francisco lost power.